



**Ozone Air Quality Effects of a  
10% Ethanol Blended Gasoline in Wisconsin**

**September 6, 2005**

A staff report from the Bureau of Air Management

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### **Purpose of the Document**

The purpose of the document is to assess the effects on ozone concentrations of a legislative proposal that requires gasoline in Wisconsin to contain 10% ethanol. We refer to this 10% blend of ethanol as E10. Due to resource constraints, we only evaluated the air quality effects on ozone concentrations. It is important to note, we did not evaluate the effects on fine-particle concentrations and visibility, nor did we analyze the air quality effects of other ethanol blends such as E6 or E85.

In this document, we assess the changes to VOC, CO and NO<sub>x</sub> emissions for the following emission source categories:

1. On-road Vehicles
2. Off-road Vehicles and Equipment
3. Portable Fuel Containers
4. Ethanol Production
5. Fuel Storage and Distribution
6. Permeation

Our analysis covers 66 counties in the state. The other six counties, Kenosha, Milwaukee, Ozaukee, Racine, Washington and Waukesha already use reformulated gasoline (RFG) that contains ethanol. An E10 mandate for the state will do little to change the gasoline sold in the Milwaukee area, since the RFG sold in the area has to meet very specific performance requirements established in the Federal Clean Air Act.

### **Findings**

The Department's analysis resulted in the following conclusions:

1. **There would be an increase in NO<sub>x</sub> emissions, an increase in VOC emissions, and a decrease in CO emissions in Wisconsin.**  
Table 1 below summarizes the projected emission changes with an E-10 mandate.
2. **In the 66 county area, the reactions that create ozone are principally limited by NO<sub>x</sub> concentrations, so only the change in NO<sub>x</sub> emissions will significantly change ozone concentrations.**
3. **A mandate to use E10 blended gasoline in Wisconsin will increase NO<sub>x</sub> emissions by about 1-2% on an average summer day.**  
The increase in NO<sub>x</sub> emissions will range from 1- 2% of the total NO<sub>x</sub> inventory for the 66 county area included in the analysis. This equates to a 6.9 – 13 ton/day increase in NO<sub>x</sub>. To put the NO<sub>x</sub> emissions increase from an E10 mandate into perspective, a 13 ton/day increase is:
  - \* Twice as much as the NO<sub>x</sub> decrease we get from the motor vehicle inspection and maintenance program in Southeastern Wisconsin; or
  - \* About as much NO<sub>x</sub> emissions as emitted by a 350 Megawatt coal-fired power plant.

4. **The net result will be an increase in ozone concentrations on the order of 1 ppb to as much as 2 ppb on a typical summer day due primarily to the increase in NOx emissions.**  
Ozone transported from non-RFG counties will exacerbate the ozone problem in the nonattainment counties in Eastern Wisconsin.
5. **The largest contributions of increased NOx emissions would be from the off-road vehicles/equipment and on-road vehicles sectors (see table 1 for details).**
6. **If an E-10 mandate becomes law in the state, in addition to other significant reductions in NOx emissions, we will need to find additional NOx reductions from other sources to offset the increase in NOx from an E10 mandate.**  
The likely emission sources include electric utilities and industrial sources. Those additional NOx emissions reductions will need to be part of our federally enforceable attainment demonstration for the 8-hour ozone standard.
7. **An E-10 mandate would not, in and of itself, result in ozone standard violations in the attainment counties in Wisconsin, but would likely result in more counties being identified in health advisories for ozone in the State.**

Table 1: 66 County Average Summer Day Emission Changes with an E10 Mandate

Emissions Source	VOC (tons/day)	CO (tons/day)	NOx (tons/day)
On-Road Motor Vehicles	8.2	100.7	-0.9 - 5.2
Off-Road Vehicles and Equipment	-3.2	-339.1	7.0
Portable Gasoline Containers	3.5	0	0
Ethanol Production	0.7	0.9	0.8
Fuel Storage and Distribution	4.8	0	0
Permeation	4.7 - 15.4	0	0
Total	18.7 - 29.4	-237.5	6.9 - 13.0

#### **Wisconsin Motor Vehicle Gasoline Use**

Ethanol used in gasoline is primarily distilled from corn. It is used as an oxygenate in RFG sold in southeastern Wisconsin (6 counties) and to increase octane levels in a portion of the conventional gasoline sold throughout Wisconsin.

The Wisconsin Energy Statistics Report shows that in 2003 the total motor vehicle gasoline use in Wisconsin increased by 0.8 percent and the use of conventional gasoline containing 10 percent ethanol by volume (E-10) increased by 2.4 percent. The 2003 figures for gasoline use in Wisconsin are shown in Table 2:

Table 2: Gasoline Usage in Wisconsin

Fuel	Thousands of Gallons	Percentage
Gasoline without Ethanol	1,692,060	64.0
Reformulated Gasoline (RFG)	717,545	27.1
E-10	235,364	8.9
Total Gasoline Sales	2,644,969	100

The US Department of Energy Petroleum Data Publication reports that, in 2003, the use of regular grade (87 Octane) gasoline in Wisconsin averaged 87 percent for both RFG and conventional gasoline. The use of mid-grade and premium grade gasoline were 5 percent and 8 percent respectively.

Note: Since the majority of fuel used in Wisconsin is 87 octane, limiting the E10 mandate to only 87 octane fuel will have little effect on our emissions calculations and it will not change our conclusions regarding the effects of E10 on ozone concentrations.

### **Effects of Ethanol as a Fuel Additive**

The effects of E10 on engine emissions are highly variable, depending on equipment type, age of equipment, year of the analysis, etc. Due to the uncertainty associated with E10 analyses, it is important to understand the assumptions that form the basis for the analysis. Our assumptions are outlined in Appendix A to this document.

Vapor Pressure: Blending gasoline with a 10% ethanol in conventional gasoline (E-10) increases the volatility of the fuel. A vapor pressure scale for gasoline blends known as Reid Vapor Pressure (RVP) is used as a gauge for the volatility of gasoline. The Federal Clean Air Act limits the summertime RVP of gasoline to 9.0 psi, but allows the gasoline to have an RVP of 10.0 psi, if the fuel is blended with 10% ethanol.

Ethanol in RFG: Ethanol added at 5.7 percent by volume to RFG complies with the Federal Clean Air Act mandated 2% by weight oxygenate requirement in RFG. The VOC emissions that result due to the ethanol blend comply with the applicable limits, because ethanol is mixed with a very low RVP base gasoline at the terminal. In the Milwaukee/Chicago/Gary markets, virtually all RFG uses a 10 percent ethanol blend with a 0.3-psi higher RVP waiver allowed by the U.S. EPA. This 10 percent ethanol blend RFG still meets all applicable reduction requirements for NO<sub>x</sub> and VOC emissions.

Commingling: Another volatility effect of ethanol is the inadvertent commingling of ethanol-containing and ethanol-free gasoline in vehicle fuel tanks. Even small amounts of ethanol raise the fuel mixture volatility, which results in increases in evaporative VOC emissions. This could be significant with the possibility of frequent commingling of ethanol blend gasoline and non-ethanol gasoline in vehicle fuel tanks and gasoline containers. In Wisconsin, commingling could occur between E10 and premium gasoline and from vehicles refueling outside the state.

Fuel Economy: E10 gasoline contains about 3% less energy per gallon because of the lower heat content of ethanol, resulting in a loss in fuel economy. Later model vehicles equipped with oxygen-sensors (built since the mid-1980s), generally show about a 2% fuel economy loss when operating on E10. In older vehicles the improvement in combustion due to the leaning-out effect of ethanol may partially compensate for the loss in energy content of the fuel and fuel economy may be only slightly degraded.

Fuel Systems Materials Compatibility: All vehicle manufacturers have upgraded their fuel systems to use up to 10 percent ethanol blend gasoline since model year 1980. Fuel systems in 1975 to 1980 model years were upgraded, but not to the same extent as later models. Pre-1975 models may have fuel system components that are sensitive to high aromatics and alcohols in gasoline

E10 gasoline could affect the fuel systems of antique, hobbyist and collector vehicles and some older non-road equipment still in use. Even if these vehicles and equipment are permitted to use

non-ethanol premium gasoline, the possibility exists that the higher price and unavailability of non-ethanol premium gasoline in remote areas or the lack of understanding that older fuel systems may be sensitive to ethanol could cause the motorist to use E10.

### **Emissions Effect on On-Road Motor Vehicles**

In motor vehicles, the magnitude of the VOC, NO<sub>x</sub> and CO emissions is critically dependent upon the technology and maintenance of the vehicle-engine burning the fuel. E10 has the most significant emissions effect in older vehicles built prior to 1986 model year that are poorly maintained. In an older vehicle with a carburetor that is poorly maintained and running on a rich air/fuel mixture, the addition of ethanol to gasoline will significantly reduce CO and tailpipe VOC emissions. However, NO<sub>x</sub> emissions will increase with the more complete and hotter combustion temperatures in the cylinder.

Emission effects are significantly reduced in newer vehicles that are well maintained and have computers adjusting the air/fuel ratio to achieve better combustion. Due to the higher fuel volatility for E10, our analysis shows increases in emissions of VOC and CO. NO<sub>x</sub> emissions are less affected, since the computers keep the engine from running too lean. The 1-psi higher RVP waiver allowed for E10 gasoline results in more evaporative VOC emissions. However, in new vehicles built beginning in model year 2004, evaporative emissions are greatly reduced.

The Northeast States for Coordinated Air Use Management (NESCAUM) reports for a typical summertime fuel in the northeast an RVP increase of 0.93 psi will result in 14 percent increase in VOC emissions. In 1998, this effect led the California Air Resources Board (CARB) evaluation to its decision not to allow a 1-psi waiver for ethanol containing fuels.

Currently in Wisconsin, about 9 % of the conventional gasoline is E10. We ran US EPA's MOBILE6.2 emissions model to compare total, highway vehicle emissions of VOC, CO and NO<sub>x</sub> for all conventional gasoline in Wisconsin blended with 10 percent ethanol and a full 1-psi RVP waiver. The Mobile 6.2 model indicates that use of E10 in Wisconsin will result in an increase of VOC emissions of 8.2 tons/day, an increase in CO emissions of 100.7 tons/day and no change in NO<sub>x</sub> emissions.

However, a recent Southeast Michigan Council of Governments' (SEMCOG) study shows that E10 may increase both VOC and NO<sub>x</sub> emissions in the Midwest. Their study used both the US EPA Complex Model and the CARB Predictive Model. Both the Complex Model and the Predictive Model simulate effects that are not included in the older and less sophisticated Mobile 6.2 model. Using the results of the SEMCOG study, we estimate changes in NO<sub>x</sub> emissions from the current use of conventional gasoline of -0.9 tons/day to an increase of 5.2 tons/day with the introduction of E10 statewide

The SEMCOG analysis includes the evaporative effect from three primary sources that use conventional gasoline; on-road vehicles, off-road equipment, and vehicles and portable fuel containers. Using the results from the SEMCOG study we estimate VOC emission increases from permeation effects on highway vehicles to be between 2.6 and 5.2 tons/day. These emission changes are also reported under "Permeation Effects" in the Table 1. When older vehicles are replaced with vehicles meeting the newer emission standards, the evaporative effects will be reduced.

### **Emissions Effect on Off-Road Vehicles and Equipment**

Off-road equipment operating on gasoline include snowmobiles, motor boats, jet skis, all-terrain vehicles, motor scooters, lawn mowers, chain saws, weed-trimmers, wood chippers, etc. Older models of these equipments have open-loop engines (both 2-stroke and 4-stroke) and some of these engines are set to run on a fuel rich air/fuel (A/F) ratio.

The addition of oxygenates to gasoline has the effect of leaning out the air/fuel mixture on these engines that do not adjust to optimize the A/F ratio. This enleanment effect can increase engine-operating temperatures for open-loop engines, such as on snowmobiles and other high performance engines, that rely on a fuel rich A/F mixture for optimum operation. High operating temperatures can create engine performance problems and increase NOx emissions.

Increase in fuel volatility from ethanol affects the emissions from off-road vehicles and equipment. For E-10 in Wisconsin, EPA's NONROAD model estimates a decrease of 339.1 tons/day of CO, a decrease of 3.2 tons/day of VOC, and an increase of 7.0 tons/day of NOx. The NONROAD model includes exhaust, diurnal, refueling and crankcase emissions, but does not account for hot-soak, running losses and resting losses. These unaccounted factors result in a significant underestimate the VOC emissions due to fuel volatility increases.

#### **Emission Effect on Portable Fuel Containers:**

In Wisconsin, it is estimated that in the household and industrial sectors there are approximately 2 million portable fuel containers. VOC emissions from portable fuel containers occur in various ways. Examples include: spills during transportation and refueling; evaporation through openings, poor seals and diurnal emissions; permeation through the container walls; and emissions associated with vapor pressure released during equipment refueling. The addition of ethanol will increase the VOC emissions from the portable fuel containers.

We estimated VOC emissions in the 66 Wisconsin counties from portable fuel containers to be 22.25 tons/day (DNR Inventory Data Analysis). For E10 with the 1-psi RVP waiver, the evaporative VOC emissions from portable fuel containers will be about 15 percent higher in summertime (NESCAUM Report), or an estimated increase of 3.3 tons/day.

#### **Emissions Effect from Ethanol Production**

Ethanol plants consume energy and generate emissions in the production cycle. Additional production and supply of ethanol will be required to meet the 10 percent ethanol requirement in all conventional gasoline in Wisconsin. Higher ethanol production to meet the E10 market will generate higher emissions of VOCs, CO and NOx.

Based on 2007 projected gasoline use in Wisconsin, we estimate that the emissions increase from the additional ethanol production required to meet gasoline demand in Wisconsin will be 0.7 tons/day of VOC, 0.9 tons/day of CO, and 0.8 tons/day of NOx. (DNR Ethanol Plant Emissions Permit Data)

#### **Fuel Distribution and Storage :**

Evaporative VOC emissions are significant in the distribution and storage of fuel. The storage and distribution functions include tank truck transit, station loading, station breathing and vehicle refueling. Ethanol blended to gasoline at the terminal will increase the volatility with increased evaporative VOC emissions from distribution and storage of the blended fuel.

Based on 2007 projected gasoline use in Wisconsin, the VOC emissions from storage and distribution of conventional gasoline is estimated at 31.77 tons/day (US 1997 Economic Census

Data and DNR 2002 Emissions Inventory). The estimation accounts for the penetration of vehicles with On-Board Refueling Vapor Recovery (ORVR) system in 2007. For E10 with the 1-psi higher RVP waiver, the summertime evaporative VOC emissions from fuel distribution and storage will increase by 15 percent (NESCAUM Report), or an estimated increase of 4.8 tons/day.

**Emissions from Permeation Effect of Ethanol:**

Ethanol increases permeation VOC emissions from non-metal fuel systems in on road vehicles, off-road vehicles and equipment and gasoline fuel containers. For E10 in Wisconsin, based on a projected 2007 gasoline use, the permeation effect increases VOC emission by 2.6 to 5.2 tons/day from on-road vehicles, 1.2 to 9.4 tons/day from off-road equipment and 0.8 tons from portable fuel containers (SEMCOG and CARB Studies).

**Conclusions - Effect on Air Quality from an Ozone Perspective**

The precursors for ozone formation are primarily VOC and NOx. CO is a secondary ozone precursor, but due to its relatively high emissions it may play a role in ozone formation.

On high ozone days, in densely populated areas, the atmosphere is often "VOC limited." In other words, there is more NOx in the atmosphere than what is needed to drive the photochemical reactions to produce ozone. VOC limited conditions occur in Milwaukee and immediately downwind. In these cases, reducing VOC and CO will be effective at reducing ozone concentrations. In less densely populated areas on high ozone days, the atmosphere is NOx limited. In other words, there is more VOC in the atmosphere than what is necessary to efficiently drive the photochemical reactions to produce ozone. In these cases, any increase in NOx emissions will increase ozone concentrations.

The vast majority, if not all, of the 66 counties in the analysis, will experience NOx limited conditions on high ozone days. The increase in NOx emissions associated with an E10 mandate will degrade air quality throughout the state. Additionally, the increased ozone will be transported into Eastern Wisconsin and exacerbate the ozone problem in the six southeastern nonattainment counties. The NOx increases of 6.9 - 13 tons/day represents a 1 - 2% increase in NOx emissions in the 66 county area. This increase in NOx emissions in the 66 county area will require obtaining additional emission reductions to compensate for the increased NOx emissions from an ethanol mandata when we develop our attainment demonstration for the 8-hour ozone standard. We are currently evaluating potential source sectors for emissions reductions with the other states in the Lake Michigan Air Directors Consortium. The current analyses indicate that electric utilities and industrial sources are the likely targets for additional NOx control programs.

Reactivity is a measure of how a pollutant reacts in the atmosphere to form a secondary pollutant such as ozone. VOCs are significantly more reactive than CO. A recent reactivity study (CARTER *et al.* 2003) shows that compared to VOCs on a weight basis, CO's contribution to ozone formation ranges from 8 to 14 percent, depending on the relative concentration of VOC and NOx. This means that given the same amount of VOCs and CO by weight, the resulting ozone from CO would only be 8 to 14 percent of the amount created by the VOCs. Applying the reactivity scale from Carter to the CO emissions, the VOC increase is "offset" by the CO decreased associated with an E10 mandate. Additionally, since these emission changes are occurring in a NOx limited atmosphere, these changes to VOC and CO emissions in the 66 county area would have, at most, only a negligible effect on ozone concentrations in the state. Therefore, changes to VOC and CO emissions will not compensate for the increase in ozone concentration associated with the increase in NOx emissions.

Figure 1 lists the design values (a three year average of the fourth highest ozone concentration at each monitoring site) for the years 2002 through 2004. To determine whether there is a violation of the ozone standard, one compares the design value to 85 ppb. A design value of 85 ppb or higher indicates a violation of the standard. Adding 2 ppb to any 2002 – 2004 design value does not result in a “new” violation of the standard. However a design value increase of 2 ppb at several critical monitors such as Sheboygan, Grafton, or Pleasant Prairie will make it much more difficult to attain the 8-hour ozone standard in Eastern Wisconsin.

Figure 1: Ozone Design Values (ppb) for 2002 – 2004 (Shaded Counties are designated nonattainment areas.)



Another way to look at the air quality effect of a 1 to 2 ppb increase in ozone concentration is to examine the effect on the number of high concentration days. We choose 85 ppb as a threshold of interest, since we issue health advisories for ozone when the 8-hour concentration is equal to or greater than 85 ppb. Appendix C presents preliminary ozone concentration data for 2005 and shows that there were 108 site-days with an 8-hour ozone concentration equal to or exceeding 0.085 ppm (85 ppb). If we added 2 ppb to each concentration of 83 or 84 ppb, the number of site days at 85 ppb or above increases to 134 or a 24% increase. We concluded that a 2 ppb increase in ozone concentrations, the upper limit of our analysis, would have resulted in more counties being included in health advisories in 2005.

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## APPENDIX A

### EVALUATION ASSUMPTIONS AND METHODOLOGY

#### Portable Gasoline Fuel Containers (PFC)

Our evaluation is based on California Air Resources Board (CARB) PFC emission projection methodology. This is the best data that there is and the Ozone Transport Commission (OTC) states have adopted the same methodology. The only adjustment for Wisconsin was the seasonal utilization of lawn and garden equipment from our off-road National Emissions Inventory (NEI) submittal in 2004. The PFC data is for 2002, which is projected to 2007 without any changes because that is the latest data we have.

The emissions inventory is an estimate of the amount of VOCs emitted from PFCs, typically used to refill residential-and-commercial, off-highway vehicles and equipment. The county-wise emissions from PFCs in Wisconsin are based on the following CARB emission factors:

Permeation - Plastic Cans	1.57 grams/gal-day
Metal Cans	0.06 "
Closed System Diurnal -Plastic Cans	1.38 "
Metal cans	0.44 "
Open System Diurnal Plastic and Metal Cans	21.8 "
Closed System Transport Spillage losses	23.0 grams/refill
Open System Transport Spillage losses	32.5 grams/refill

The assumptions made for PFC emission estimates for Wisconsin from gas container survey results:

	Residential	Commercial
% with at least 1 gas can	46%	80%
# of gas cans per unit	1.8	6.9
% of plastic gas cans	76%	72%
% of metal gas cans	24%	28%
Weighted average gas can capacity (gal)	2.34	3.43
Percentage of gas cans stored with fuel	70%	70%
Weighted ave. stored fuel volume (% of Total Cap)	49%	49%
% of total gas cans that are plastic - stored open 23%		39%
% of " - stored closed	53%	33%
% of total gas cans that are metal - stored open 11%		10%
% of " - stored closed	13%	18%
% of all gas cans stored open (Plastic + Metal)	34%	49%
% of " closed (Plastic + Metal)	66%	51%
Ave. # refills per year	6.4	
Ave. # of refills per day	0.0174	
Ave. # refills/year for lawn & garden equipment		351.8
Ave. # refills/day "		0.964
Ave. # refills/year for non-lawn and garden equipment		43.8
Ave. # refills/day		0.12"

Based on these emission factors, assumptions and projection of 2002 data to 2007 -  
 Total VOC evaporative emissions estimate from PFCs for the 66 counties in Wisconsin with convention gasoline  
 = 24.165 tons/hot summer day.  
 Spillage is constant and not considered to change any emissions variations with E-10 -  
 Total VOC emissions from PFCs for the 66 Wisconsin counties without considering spillage  
 = 22.25 tons/hot summer day  
 Considering a 15% VOC emissions increase in summertime with 1-psi RVP increase (NESCAUM report) -  
 VOC increase estimated from PFCs in the 66 Wisconsin counties with E-10 in 2007-  
 = 3.3 tons/hot summer day

Summer Day Plastic Permeation VOC Emission Estimates

Assumptions:

1. Permeation emissions from metal gas cans are negligible and therefore excluded
2. To estimate summer day emissions, the seasonal adjustment factor from NMIM for lawn & garden equipment (excluding chain saws) is applied. This assumes that 50.1 percent of annual activity occurs during the 92 day summer period. Hence, 50.1 percent of the gas can emissions occur during this period.
3. Using CARB estimates, plastic gas can permeation VOC emissions increase by 45 percent from E-6.
4. Assuming that E-6 and E-10 emissions are the same (a poor assumption, but it is the most realistic data available and the emissions could likely be underestimated).

For 72 counties, the total permeation VOC emissions = 2.858 tons/summer day

For 66 counties, the total permeation VOC emissions = 1.898 tons/summer day

Assuming CARB's permeation estimate for E-6,  
 45% permeation VOC increase in 66 counties = 0.9 tons/summer day

**Projected Effects of Ethanol Blends on On-Road Emissions In the 66 Counties of Wisconsin without Reformulated Gasoline**

**Year: 2007**  
**Emission Units: Tons per Summer Weekday**

Pollutant	(Base Case) 10% E10 Market Share	100% E10 Market Share					
	Total Emissions*	Total Emissions*		Change from Base Case			
	(tons)	Low (tons)	High (tons)	Low (tons)	High (tons)	Low (%)	High (%)
VOC	145.2	156.0	158.6	10.8	13.4	7.4%	9.2%
CO	1839.7	1940.4	1940.4	100.7	100.7	5.5%	5.5%
NOx	340.0	339.1	345.1	-0.9	5.1	-0.3%	1.5%

\* Emissions include those from both gasoline-powered and diesel-powered vehicles.

NOTES:

I. GENERAL

The MOBILE6.2 model was used to model the base case emissions. That model was also used as a starting point for modeling the "100% E10 Market Share" emissions. (Some off-model adjustments were made for VOC and NOx, as described below.)

In both the base case and the "100% E10 Market Share" case, the gasoline Reid Vapor Pressure (RVP) was assumed to be 8.7 psi (before ethanol was added). A 1 psi RVP waiver for ethanol blends was also modeled for both cases.

II. VOC EMISSIONS

The VOC emission changes due to the increased ethanol include the permeation emissions resulting from the additional ethanol. Two sources of information were used to calculate the additional permeation emissions. Thus, there are "Low" and "High" values:

The "Low" value is based on data (permeation emissions by vehicle class) presented by Air Improvement Resources, Inc., (AIR) at the Lake Michigan Air Directors Consortium (LADCO) on March 8, 2005. From these data, WDNR calculated an emission factor (applicable to the Wisconsin fleet) of a 0.72 gram/day/vehicle increase in VOC permeation due to ethanol.

The "High" value is based on data in a draft February 2005 report by the California Air Resources Board (CARB). From those data, WDNR calculated a 1.42 gram/day/vehicle increase in VOC permeation due to ethanol.

A summary of the VOC permeation emissions resulting from a change from 10% E10 (base case) to 100% E10 follows:

Low Value (derived from AIR data): 2.6 tons (1.8% of total Base Case VOC)  
High Value (derived from CARB data): 5.2 tons (3.6% of total Base Case VOC)

In addition to increasing VOC permeation emissions, going to 100% ethanol is also estimated to increase non-permeation VOC emissions by 8.2 tons per summer weekday. The MOBILE6.2 model was used to calculate this increase. Thus, the total change in VOC emissions from going to 100% ethanol is:

Low Value: 2.6 tons + 8.2 tons = 10.8 tons (7.4% of total Base Case VOC)  
High Value: 5.2 tons + 8.2 tons = 13.4 tons (9.2% of total Base Case VOC)

III. CO EMISSIONS

The MOBILE6.2 model was used to calculate the CO emissions for both cases. No range of values was calculated.

A critical modeling input for the ethanol effect on CO is the Reid Vapor Pressure (RVP). A RVP of 8.7 psi (with a 1 psi waiver for ethanol blends) was used in this analysis. This

resulted in an increase in CO from ethanol. Test runs using MOBILE6.2 for RVPs ranging from 6.8 to 9.2 psi (before E10 is added) indicate that ethanol decreases CO when the gasoline RVP is 8.2 psi or less and that ethanol increases CO when the gasoline RVP is 8.3 psi or more.

#### IV. NOX EMISSIONS

The MOBILE6.2 model does not model the effect of ethanol on NOx emissions. To estimate the effect of ethanol, data were utilized from the report: Emission Reductions from Changes to Gasoline and Diesel Specifications and Diesel Engine Retrofits in the Southeast Michigan Area, February 23, 2005, by Air Improvement Resource, Inc. That report includes two separate estimates of the change in NOx from ethanol. One estimate used the U.S. EPA's Complex Model while the other estimate used CARB's Predictive Model. The Complex Model showed that ethanol decreases NOx emissions by about 0.6% while the Predictive Model showed that ethanol increases NOx emissions by about 3.6%. These percentages were applied to the NOx emissions from gasoline-powered vehicles in the Wisconsin 66-county area. This resulted in the following changes in NOx emissions from 10% E10 (base case) to 100% E10:

Low Value (from Complex Model):	-0.9 tons
High Value (from Predictive Model):	+5.1 tons

#### **Nonroad Emissions Excluding Permeation Emissions**

The National Mobile Inventory Model (NMIM) that incorporates the NONROAD 2004 draft (NONROAD) model is used to estimate emissions from nonroad gasoline fueled vehicles. Nonroad sources are equivalent to off-road mobile sources. Examples of nonroad sources include recreational equipment (e.g. off-road motorcycles and snowmobiles), construction and mining equipment (e.g. cranes and graders), industrial equipment (e.g. forklifts and sweepers), lawn and garden equipment (e.g. lawn mowers and small chain saws), agricultural equipment (e.g. tractors and tillers), commercial equipment (e.g. pumps and pressure washers), logging equipment (e.g. large chain saws and large shredders) and recreational marine equipment (e.g. inboards and outboards). However, the NONROAD model doesn't estimate emissions from the following nonroad sources: commercial marine vessels, aircraft and locomotives.

The NONROAD model estimates the following types of nonroad emissions: exhaust, diurnal evaporative, refueling and crankcase. Fuel oxygenate content is incorporated into the emissions calculations for these four types of emissions. For diurnal evaporative emissions, fuel oxygenate content is included in the emissions calculation by manually adjusting the Reid Vapor Pressure (RVP) in the NONROAD model inputs. The 2007 average summer day emissions for all Wisconsin counties excluding Kenosha, Milwaukee, Ozaukee, Racine, Washington and Waukesha counties (i.e. 66 counties) are listed in Table 1. Two sets of emissions are presented in Table 1. The first set of emission values assumes an E-10 (i.e. gasoline containing 10% ethanol) market share of 10%. The second set assumes an E-10 market share of 100%.

The NONROAD model doesn't calculate some types of nonroad emissions: hot soak, running losses, resting losses and permeation. The next version of the NONROAD model may include hot soak, running losses and resting losses emissions estimates. However, permeation emissions will need to be addressed outside of the NONROAD model in the foreseeable future. Estimates of permeation emissions are discussed in a separate section.

The NONROAD model doesn't calculate emissions due to the commingling effect. The commingling effect occurs when more than one type of gasoline is mixed in a fuel tank. The resulting mixture of gasoline can be more volatile than the individual gasoline before they were combined.

### **Nonroad Permeation Emissions**

A rough estimate of the change of nonroad permeation emissions due to the addition of ethanol to gasoline is calculated using the results of a Southeast Michigan Council of Governments (SEMCOG) study<sup>1</sup>. For our permeation emissions estimate, the decrease in VOC exhaust and evaporative emissions from increasing the E-10 market share from 25% of the market to 100% of the market is assumed to be proportional to the increase in permeation emissions due to the same increasing E-10 market fraction. From the SEMCOG study, for each ton per average summer day (tpd) decrease in VOC exhaust and evaporative emissions, the permeation emissions increase by ~ 0.4 tpd. See Tables 1 and 2. A number of caveats should be considered when using this method for estimating the change of nonroad permeation emissions.

- The market share for all Wisconsin counties excluding Kenosha, Milwaukee, Ozaukee, Racine, Washington and Waukesha counties for E-10 would increase from 10% not 25% to 100% with the proposed legislation.
- The permeation emissions estimates are based on E-6 (i.e. gasoline containing 6% ethanol) not E-10.
- Nonroad equipment types included are limited to small nonroad engines ( i.e. < 25hp) such as lawn and garden equipment, recreational marine; and recreational vehicles.

Another estimate of the change of nonroad permeation emissions due to the addition of ethanol can be calculated using a working draft of California Air Resources Board (CARB) study. When E-6 was substituted for gasoline without ethanol, this study determined that evaporative emissions were increased by approximately 49% due to permeation for small nonroad gasoline engines (less than or equal to 25 hp). The study excluded recreational vehicles such as ATVs and recreational marine vehicles such as outboards. Limiting the nonroad engines to this subset, the change in permeation emissions for the 66 Wisconsin counties is 2.9 tpd. If the assumption of a 49% increase in evaporative emissions due to permeation is extended to all nonroad gasoline engines, the change in permeation emissions for the 66 Wisconsin counties is 9.4 tpd. The changes in permeation emissions values are summarized in Table 2. Again, a number of caveats should be considered when using this method for estimating the change of nonroad permeation emissions.

- The permeation emissions estimates are based on E-6 not E-10.
- Nonroad equipment types included are limited to small nonroad engines less than or equal to 25 hp) such as lawn and garden equipment.
- The meteorological conditions in California can differ significantly from Wisconsin meteorological conditions.

All of these caveats imply that significant additional study into permeation emissions is needed to improve the existing estimates and to create new estimates for unquantified parts of the nonroad sector. More refined, accurate and diverse factors for calculating nonroad permeation emissions should be available within the next year from research being conducted by CARB and others.

Table 1: 2007 Nonroad Emissions Summary for 66 Wisconsin Counties  
(tons per average summer day)

E-10 Market Share	CO	NOx	Exhaust and Evaporative VOC	Permeation VOC
100%	1,342.7	24.2	219.0	-
10%	1,681.8	17.2	222.2	-
Change from Increase in E-10 Market Share	-339.1	7.0	-3.2	1.2 up to 9.4*

\* See Table 2

Table 2: Changes in 2007 Nonroad Permeation Emissions for 66 Wisconsin Counties from Increase in E10 Market Share  
(tons per average summer day)

Source	Permeation VOC
SEMCOG Study	1.2
CARB Study - Small Nonroad Gasoline Engines	2.9
CARB Study - All Nonroad Gasoline Engines	9.4

## References

1. "Emission Reductions from Changes to Gasoline and Diesel Specifications and Diesel Engine Retrofits in the Southeast Michigan Area", AIR, Inc. for SEMCOG, February 23, 2005.

## Fuel Storage and Distribution

The evaluation of the VOC emissions from Fuel Storage and Distribution is based on our off-road National Emissions Inventory (NEI) submittal in 2004. The NEI data is for 2002 gasoline use but has been projected out to 2007 without any change for evaluation purpose. If the actual gasoline use in 2007 is higher, then higher emissions can be expected from fuel storage and distribution.

The emissions inventory is an estimate of the amount of VOCs emitted by the total gasoline use from Tank Truck Transit losses, Station Loading losses, Station Breathing losses and Vehicle Refueling losses. Stage I control in 20 counties and Stage II control in 9 counties are factored in to the emission evaluations. The county-wise emissions by each category are based on the following emission factors:

### Base Emission Factors:

Tank Truck Transit (loaded with gasoline)	0.005 lb. VOC / 1000 gal. gasoline
Tank Truck Transit (return with vapor)	0.055 lb. VOC / 1000 gal. gasoline
Splash underground tank filling (Stage I)	11.5 lb. VOC / 1000 gal. gasoline
Submerged underground tank filling (Stage I)	7.3 lb. VOC / 1000 gal. gasoline

Vapor balance underground tank filling (Stage I)	0.3 lb. VOC / 1000 gal. gasoline
Underground tank breathing and emptying	1.0 lb. VOC / 1000 gal. gasoline

Total gasoline usage 2,625,662 x 1000 gal.

Gasoline transportation adjustment factor	1.25
Seasonal adjustment factor - summer (6/1-8/31)	1.157
Winter (12/1-2/28)	1.006

Fraction of fuel sold -	summer	0.2891
	Winter	0.2514
	5/15-9/15	0.3650
	9/16-11/15 & 3/16-5/14	0.3215
	11/16-3/15	0.3135

Daily and Hourly Allocation	Daily(days/week)	Hourly(hours/day)
Trucks in Transit	6	24
Fuel delivery to outlets	6	24
Vehicle refueling	7	24
Storage Tank breathing	7	24

	Stage I	Underground tank breathing and emptying
Rule Effectiveness	98%	100%
Rule Penetration	100%	100%
Control Efficiency	97.39%	82.20%

Vehicle refueling emission factors (grams VOC / gal. of gasoline)	Summer	2007 ORVR	Spring & Fall	Winter
	(5/15-9/15)	Penetration	(9/16-11/15 & 3/16-5/14)	(11/16-3/15)
Conventional gas / no Stage II	3.02	1.7	3.20	3.49
Conventional gas / Stage II	0.92	0.6	0.96	1.03
Reformulated gas / Stage II	0.72		0.96	1.03

Based on these emission factors, inputs and projection of 2002 data to 2007 On-Board Refueling and Vapor Recovery (ORVR) penetration -

Total 2007 VOC emissions estimate from storage and distribution (s & d) of conventional gasoline in the 66 Wisconsin counties = 31.77 tons/hot summer day

Considering a 15% VOC emissions increase in summer with 1-psi RVP increase (NESCAUM report) -

VOC emissions increase estimated from s & d of fuel with E-10 in 66 Wis. counties = 4.8 tons/hot summer day

## Wisconsin Emissions Data

### 2002 Wisconsin Emissions Inventory - 07/21/2005 Base J (tpy)

	<b>CO</b>								
	Nonroad-Diesel	Nonroad-Non-Diesel	Point-EGUs-Coal	Point-EGUs-Non-Coal	Point-Non-EGUs	Area	Onroad-Diesel	Onroad-Non-Diesel	Totals
NAA	5,040	182,646	4,958	247	4,904	43,486	2,965	316,620	560,866
Collar counties	5,253	132,833	456	431	7,764	36,379	4,048	393,723	580,887
Other counties	11,053	259,671	4,284	457	21,843	76,594	6,254	541,010	921,166
<b>totals</b>	<b>21,346</b>	<b>575,150</b>	<b>9,699</b>	<b>1,135</b>	<b>34,511</b>	<b>156,460</b>	<b>13,267</b>	<b>1,251,352</b>	<b>2,062,919</b>

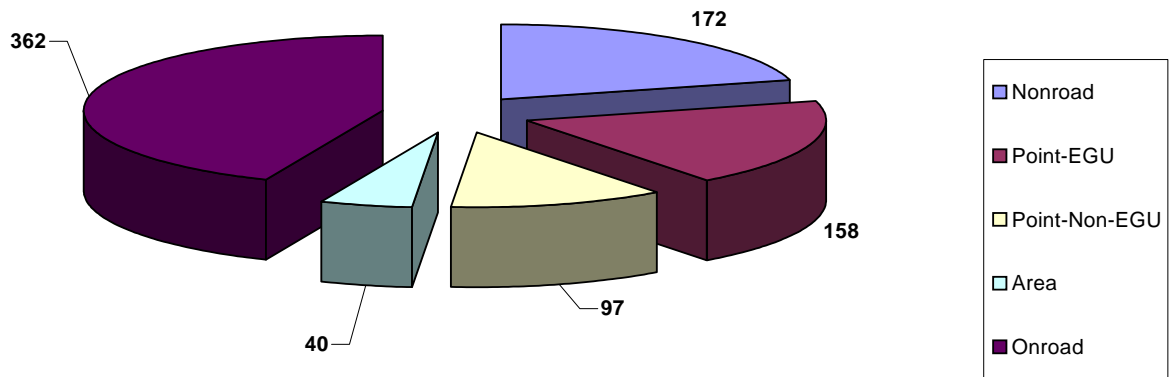
  

	<b>NOx</b>								
	Nonroad-Diesel	Nonroad-Non-Diesel	Point-EGUs-Coal	Point-EGUs-Non-Coal	Point-Non-EGUs	Area	Onroad-Diesel	Onroad-Non-Diesel	Totals
NAA	12,984	8,287	42,104	340	3,616	8,316	17,937	22,179	115,762
Collar counties	12,004	4,274	9,686	1,106	13,449	6,155	25,588	24,229	96,490
Other counties	34,731	6,677	36,396	886	21,406	7,445	42,679	33,307	183,528
<b>totals</b>	<b>59,719</b>	<b>19,238</b>	<b>88,186</b>	<b>2,332</b>	<b>38,471</b>	<b>21,915</b>	<b>86,203</b>	<b>79,715</b>	<b>395,779</b>

	<b>VOC</b>								
	Nonroad-Diesel	Nonroad-Non-Diesel	Point-EGUs-Coal	Point-EGUs-Non-Coal	Point-Non-EGUs	Area	Onroad-Diesel	Onroad-Non-Diesel	Totals
NAA	1,133	16,744	358	12	6,629	71,355	559	17,759	114,550
Collar counties	1,157	13,769	58	21	11,545	61,079	742	21,057	109,430
Other counties	2,671	61,737	333	195	14,221	83,952	1,119	27,514	191,742
<b>totals</b>	<b>4,961</b>	<b>92,250</b>	<b>749</b>	<b>228</b>	<b>32,396</b>	<b>216,387</b>	<b>2,421</b>	<b>66,331</b>	<b>415,722</b>

# 2002 66-County NOx Emissions - Base J Emissions Inventory (tpd)



## **APPENDIX B**

### **BIBLIOGRAPHY SUMMARY AND ANALYSIS**

#### **1. California Air Resources Board (CARB) Draft Report, February 2005 - A Summary of the Staff's Assessment regarding the Effect of Ethanol in California Gasoline on Emissions**

This report summarizes CARB staff's assessment from a test program regarding the impact of ethanol in California Phase 3 reformulated gasoline (CaRFG3) in the emissions of hydrocarbons (HC), oxides of nitrogen (NOx) and carbon monoxide (CO). With the ban of MTBE in gasoline in California, due to its potential impact on ground and surface water, ethanol became the only approved oxygenate viable for use in gasoline. The test program was designed to determine the magnitude of the permeation effects of ethanol on non-metal automotive fuel systems from three fuels, containing either MTBE, ethanol, or no oxygenate.

The report's findings were:

1. The presence of ethanol in gasoline results in significant increase in the permeation of gasoline constituents through the motor vehicle fuel system soft components. This increases evaporative HC emissions.
2. The addition of oxygenates to CaRFG3 to comply with the federal 2 percent oxygen requirement results in about 3 percent higher NOx emissions than a non-oxygenated CaRFG3.
3. The addition of oxygen into gasoline reduces CO emissions.

#### **Analysis:**

This test program in this report was initiated as a follow-up from CARB's waiver request to U.S. EPA from the 2 percent oxygen requirement in RFG. The findings are that permeation emissions of hydrocarbon from ethanol blend gasoline in non-metal automotive fuel systems are significant. This major source of emissions has not been taken into account previously. Permeation is a component of the daily evaporative emissions from a vehicle but the effect due to ethanol use was not adequately quantified.

However, the results of this report does have some limitations if applied on a wider scale - 1) It does not assess permeation emissions from non-automotive sources such as fuel storage and distribution, portable storage containers, etc. 2) The test program does not take into account the 1 pound Reid Vapor Pressure (RVP) waiver for ethanol blend in conventional gasoline, as the testing was only with CaRFG3 and California has repealed the 1 pound RVP waiver for ethanol. 3) The test program was with 5.7 percent ethanol blend (termed E-6) in CaRFG3 and 10 percent ethanol blend (E-10) was not tested for permeation effect. 4) The California EMFAC2000 mobile source emission inventory model used in this study has its strengths and weaknesses when compared with US EPA's MOBILE6 model. 5) The test program did not include any LEV II compliant vehicles with lower evaporative emission standards to assess the permeation emissions from these vehicles.

**2. Carter, William P.L. - Investigation of VOC Reactivity Effects using Existing Regional Air Quality Models, April 17, 2003. Report to American Chemistry Council.**

The paper primarily addresses the concern among policy makers and researchers that relative reactivities of Volatile Organic Compounds (VOCs) towards ozone formation may be significantly different on a regional scale than indicated by previous modeling studies of urban scenarios. This difference may result in degradation of regional ozone levels, if reactivity-based VOC levels should be adopted.

The study shows that although there are some differences between urban and regional-scale relative reactivities, the relative reactivity rankings are generally preserved for major types of VOC species that contribute to ozone formation. In large-domain regional scenarios, long-range transport and multi-day effects can be more critical in affecting ozone formation over wide regions. Meteorology, transport and other dynamic processes are not well represented in the EKMA model used for ozone formation. The study infers that NO<sub>x</sub> control is necessary to address the need to reduce ozone exceedances in non-urban areas, though VOC control will still be necessary to reduce ozone in some urban areas, at least in the near to mid term. Reactivity based VOC controls with the most appropriate reactivity metric needs to be carried out in conjunction to NO<sub>x</sub> controls for effective ozone control measures.

Analysis:

This recent paper shows that ozone formation is a much more complex process than what the current modeling indicates. The reactivity factors of the various VOC emission constituents have a major impact to ozone formation. Even CO is an reactive ozone pre-cursor to a limited extent. The adoption of a reactivity scale by the US EPA will minimize some of the uncertainties associated with current modeling predictions.

The conclusion from the paper is that, depending on the regional ozone reactivity metrics used, ozone formation can be either VOC-sensitive or NO<sub>x</sub>-sensitive. Ozone control measures then have to be developed accordingly. In regions with high VOC-sensitivity, particularly urban areas, NO<sub>x</sub> control is counter-productive. In rural regions, which are primarily NO<sub>x</sub>-sensitive, VOC control can be counter-productive.

### **3. Northeast States for Coordinated Air Use Management (NESCAUM) Report, July 2001 - Health, Environmental and Economic Impacts of adding Ethanol to Gasoline in the Northeast States**

This study is a continuation of the earlier studies undertaken over last several years by the Northeast States to better understand the consequences of potentially introducing million of gallons of ethanol into the region's reformulated gasoline (RFG) pool. About three-quarters of all gasoline currently sold in the region is RFG.

The study assesses the potential public health, environmental, regulatory and economic impacts associated with a shift from MTBE to ethanol in RFG. Of primary concerns studied were air-quality impacts, the potential impact of ethanol in water resources, infrastructure requirements, and the economic cost of introducing ethanol. It develops recommendations to alleviate or minimize any potential adverse effects associated with significant increase in fuel ethanol use. In response to growing interest, the study also re-summarizes available information on the potential for developing biomass ethanol production capacity in the northeast. This study highlights key findings of the earlier NESCAUM analyses and provides research and broad policy recommendations for consideration by the Northeast States. The evaluation is intended to provide the member states with timely policy guidance and the information summarized provides compelling justification for the technical findings and policy recommendations that follow.

#### Analysis:

In response to the threat of MTBE contamination of the region's supply, the Northeast States were seeking ways to eliminate MTBE from RFG without losing the air quality benefits from the RFG program. Since ethanol is the only other viable substitute for MTBE, the northeast states were trying to understand the consequences of shifting to ethanol and make policy decisions accordingly.

The policy recommendations in this study, based on the findings and analyses are comprehensive and very well presented. The shift from MTBE to ethanol in RFG in the Northeast will come with air quality, public health, environmental and economic consequences. However, they can be adequately managed through informed legislation, regulation and program implementation. These policies can also be implemented at considerable cost savings with a proactive approach, more research and field studies on the health and environmental effects of ethanol fuel, further infrastructure cost studies, regional monitoring and assessment programs, appropriate emissions inventory modeling, and exploring ethanol production from biomass in the region.

#### **4. Northeast States for Coordinated Air Use Management (NESCAUM) Report, August 1999 - RFG / MTBE Issues and Options - Phase II**

The report evaluates the health, environmental and economic impacts associated with large-scale increase in the northeast region's use of ethanol. The report focuses on air-quality related health impacts and economic impacts associated with changes in fuel formulation and infrastructure needs. It also covers the potential for developing biomass ethanol production capacity (based on feedstock other than corn) in the northeast.

The first section of the report discusses the impact of curtailing or banning the use of MTBE in terms of fuel formulation, demand for different fuel constituents, and the fuel and emission characteristics.

The second section then addresses the air quality related health risks associated with increased exposure to ethanol, as well as the health impacts associated with toxic and criteria pollutant emissions from ethanol based gasoline.

The third section assesses the potential economic and regulatory impacts of a larger scale shift to ethanol to meet the oxygenate requirements of the RFG program in the Northeast, including the need for new or modified transportation, storage and distribution infrastructure.

The final section covers the development of indigenous ethanol production capacity using biomass feedstocks other than corn, which could substantially affect the economics, as well as the environmental impacts of ethanol use in the Northeast.

#### Analysis

The report is a very comprehensive analysis of the impact of substituting ethanol for MTBE in RFG in the Northeast region. However, the inferences made in this analysis are from available scientific literature prior to 1999. Many of the emission test results predate the commercial availability of RFG and do not reflect the differences in composition of gasoline blends currently in use, particularly with respect to vapor pressure performance standards. Also, past studies have typically focused on MTBE blends. Majority of the studies on the subject of ethanol usage as an oxygenate was performed on either blending ethanol to conventional gasoline, which was the only gasoline available at that time or a blend of gasoline that approximated the composition of RFG. Very few studies specifically examined ethanol as a gasoline oxygenate and its effect on vehicle emissions.

The NESCAUM study also emphasizes the need for more sophisticated modeling techniques for emissions inventory development. The inference is that the complex model used for RFG emissions is a tool developed to determine regulatory compliance, not emissions inventories.

Finally, the analysis in this study of the potential economic and regulatory impacts of a large scale shift to ethanol, including the need for new or modified transport, storage and distribution infrastructure pertains primarily to the Northeast states and the cost analysis is based on pre-1999 fuel prices. Today's high fuel prices outdate the cost analysis in this study.

## **5. Southeast Michigan Council of Governments (SEMCOG), February 2005 - Emission Reductions from changes to Gasoline and Diesel Specifications and Diesel Engine Retrofits in the Southeast Michigan Area**

This report studies the emissions reduction potential of different gasoline and diesel fuel formulations for the eight counties in southeast Michigan, designated as marginal non-attainment area for the 8-hour ozone standard. The emissions reduction potential for each option were evaluated and quantified. The options in the list were designed to provide perspective of the emissions potential of the various fuel formulations. The study is as comprehensive as possible, which in some cases, included assessments of the same fuel using different modeling tools. The use of different models allowed for a more complete perspective and provided users the opportunity to evaluate results in light of each model's strengths and weaknesses. For each of the gasoline and diesel scenarios, expected fuel properties in southeast Michigan were determined for the year 2007 and later timeframe, taking into account controls required by the U.S. EPA. In addition, estimates of ethanol gasoline blends on permeation emissions from non-metal automotive fuel systems and portable gasoline containers were incorporated in the study utilizing the recent Coordinating Research Council (CRC) study data in making these estimates.

### Analysis

The report is very comprehensive to enable SEMCOG to analyze the different gasoline and diesel fuel formulation options for implementation.

However, there are some limitations of the options as discussed in the report to reflect the uncertainties in the emissions inventory analysis. These are:

1. The difference in emissions inventory, especially for NO<sub>x</sub> between the US EPA Complex Model and the California Predictive Model.
2. The impact of likely sulfur control properties for the different gasoline options.
3. The ethanol permeation effect is based on California E-6 fuel rather than E-10 fuel in Michigan.
4. The effect of ethanol CO emissions and their impact on ozone formation.
5. The effect of lower volatility fuel on off-road equipment and portable containers.
6. The effect of diesel fuel cetane level changes on light duty diesel vehicles and in off-road application of on-road fuel.
7. The impact of composition and sulfur control properties in CARB diesel fuel and changes to emission estimates.
8. The benefits of biodiesel are from old US EPA guidance, which is probably out of date.
9. The estimates of emissions reduction from diesel retrofits are based on the assumption that the durability of the retrofit equipment is expected to last the remainder of each vehicle's life.

