Final Report

Emission Reductions from Changes to Gasoline and Diesel Specifications and Diesel Engine Retrofits in the Southeast Michigan Area

For:

Southeast Michigan Council of Governments (SEMCOG)
Alliance of Automobile Manufacturers (Alliance)
American Petroleum Institute (API)

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Table of Contents

Index of Acronyms and Abbreviations

AIR	Air Improvement Resource, Inc.
API	American Petroleum Institute
ASTM	American Society of Testing and Materials
B5	Diesel fuel with 5% biodiesel, by volume
B20	Diesel fuel with 20% biodiesel, by volume
CAA	Clean Air Act
CARB	California Air Resources Board
CaRFG	California Reformulated Gasoline
CO	carbon monoxide
CRC	Coordinating Research Council, Inc.
DI	Driveability Index
DOC	Diesel Oxidation Catalysts
EGR	Exhaust Gas Recirculation
E10	Gasoline with 10% ethanol by volume
E6	Gasoline with 6% ethanol by volume
EPA	(United States) Environmental Protection Agency
FTP	Federal Test Procedure
g/mi	grams per mile
HC	hydrocarbons
HDPE	high-density polyethylene
LDGV	Light-Duty Gasoline Vehicle
LDT	Light-Duty Truck
LED	Low-Emission Diesel
LEV	Low-Emission Vehicle
MDEQ	Michigan Department of Environmental Quality
MOU	Memorandum of Understanding
MTBE	methyl tertiary butyl ether
NAAQS	National Ambient Air Quality Standards
NLEV	National Low-Emission Vehicle
NOx	oxides of nitrogen
PM	Particulate Matter
PM2.5	Particulate Matter </= to 2.5 micrometers
ppm	parts per million
psi	pounds per square inch
PZEV	Partial-Zero Emission Vehicle
RFG	ReFormulated Gasoline
RFP	Request For Proposal
RVP	Reid Vapor Pressure or volatility
SEMCOG	Southeast Michigan Council of Governments
SIP	State Implementation Plan SULEV Super-Ultra-Low Emission Vehicle
T50	Temperature at which 50% of the fuel is evaporated
The Alliance	The Alliance of Automobile Manufacturers
TLEV	Transitional-Low Emission Vehicles
TSD	Technical Support Document

ULEV	Ultra-Low Emission Vehicle
ULSD	Ultra-Low Sulfur Diesel
VOC	volatile organic compound

Emission Reductions from Changes to Gasoline and Diesel Specifications in the Southeast Michigan Area

1.0 Executive Summary

Background

On April 15, 2004, the U.S. Environmental Protection Agency (EPA) finalized its list of 8-hour ozone nonattainment areas. Eight counties in Southeast Michigan were designated as a "moderate" nonattainment area. Under EPA rules, moderate areas have until 2010 to attain the 8-hour ozone standard. Moderate areas must also implement a vehicle inspection program if they do not already have one, and reduce ozone precursors by 15%.

Subsequently, the Southeast Michigan Council of Governments (SEMCOG) and the Michigan Department of Environmental Quality (MDEQ) requested a reclassification from the EPA to a marginal nonattainment area. EPA approved this request on September 15, 2004. Marginal areas are not required to implement vehicle inspection programs or implement a 15% reduction in emissions by 2010, but they must attain the ozone standard by 2007. SEMCOG's and MDEQ's request for reclassification did not change their commitment to attain the standard, but it did give them additional flexibility with regard to the control strategies it can pursue in order to meet the standard.

To ensure that the Southeast Michigan area attains the ozone standard as soon as possible, SEMCOG has been studying ways to reduce ozone precursors. As a part of this effort, it initiated a study of the emission reduction potential of different gasoline and diesel fuel formulations. SEMCOG formed a stakeholder group consisting of representatives with expertise from the oil industry, automobile industry, the Michigan Department of Agriculture and the Michigan Department of Environmental Quality to provide guidance to the study. SEMCOG contracted with Air Improvement Resource, Inc. (AIR) to quantify emission reductions that would result from various changes to fuels.

Method

In order to focus the study, the stakeholder group agreed to evaluate the emission reduction benefits of the following list of fuels and related controls. The options on the list were designed to provide a broad perspective of the emission reduction potential of various fuels. Nothing should be presumed about the feasibility or desirability of any option simply because it was analyzed in this study. For instance, several of the fuels studied are currently only available in California, while several others are not manufactured or used anywhere in the U.S.

Gasoline

- California reformulated gasoline (Ca RFG)
- Federal reformulated gasoline (RFG)
- Lower sulfur gasoline (10 ppm average)
- Lower volatility gasoline (limit of 7.0 psi Reid vapor pressure (RVP))
- A range of ethanol market penetrations (0 and 100% of a 10% ethanol blend)

Diesel

- California (CARB) diesel
- High cetane diesel
- Biodiesel (5% and 20%, or B5 and B20)
- In-use diesel engine particulate matter (PM) retrofits

The stakeholders desired that the study be as comprehensive as possible which, in some cases, included assessments of the same fuel using different modeling tools. These include EPA's MOBILE 6.2, NONROAD, and Complex models, as well as California's Predictive Model. The use of these 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 2007 and later timeframe, taking into account controls required by the EPA. In the case of the gasoline scenarios, these fuel properties were used in the Complex and Predictive Models to estimate the percent change in exhaust emissions of volatile organic compounds (VOC), oxides of nitrogen (NOx), carbon monoxide (CO), and fine particulate matter (PM2.5) from the Michigan baseline gasoline. These percent reductions were then applied to MOBILE6.2-generated exhaust emissions to estimate the changes in exhaust emissions. Changes in evaporative emissions, except permeation impacts of ethanol, were estimated directly with the MOBILE6.2 model. Emissions from off-road equipment and off-road vehicle sources were estimated with the EPA NONROAD model.

A recent study by the Coordinating Research Council (CRC) indicates that ethanol increases permeation of VOC emissions from non-metal fuel systems found on on-road and off-road vehicles, other off-road equipment, and portable gasoline containers. Estimates of ethanol blends on permeation emissions from these sources were incorporated in this study, and these estimates utilized these CRC data in making these estimates.

Baseline Inventory

Baseline inventories for on-road and off-road sources are shown in Table ES-1. The table shows that VOC emissions from on-road sources will decline by 71 tons per day (40%) from 2002 to 2007, and that NOx will decline by 184 tons per day (40%). There are also significant reductions of VOC and NOx from off-road sources. The CO inventory for on-road vehicles is projected to decline very significantly, but CO from off-road sources is projected to increase somewhat. The majority of the emission reductions shown in Table ES-1 result from the phasing-in of existing federal regulations.

Table ES-1. Baseline On-Road and Off-Road Inventories for Southeast Michigan (Gasoline and Diesel – Tons per Summer Day)

	On-Road				Off-Road			
Year	VOC[1]	NOx	PM2.5[2]	CO	VOC[1]	NOx	PM2.5[2]	CO
2002	177	463	7.1	2412	66	69	6.1	1034
2007	106	279	4.2	1257	49	58	5.2	1119
2010	86	211	3.1	1094	40	48	5.1	1145
2015	62	114	2.0	906	35	40	5.1	1196
2020	54	71	1.6	848	35	40	5.3	1281

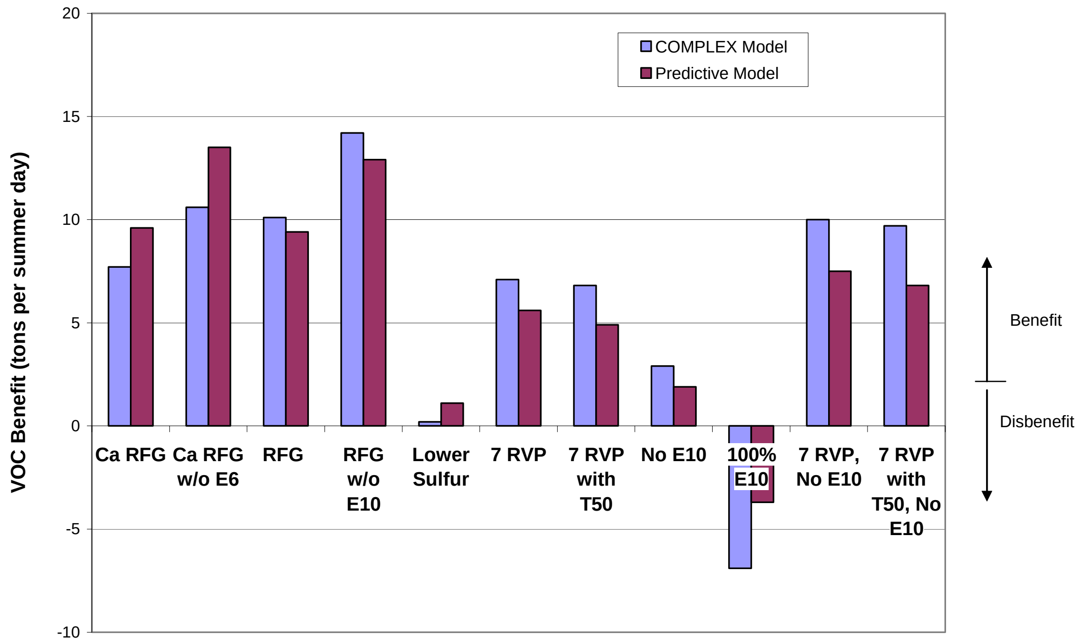
[1]Includes both exhaust and evaporative emissions but does not include any increase in permeation VOC emissions due to current ethanol market fraction of 25%.
[2]Exhaust emissions only

The VOC values in Table ES-1 do not include the increased permeation emissions from the portion of Southeast Michigan gasoline that contains ethanol (approximately 25%). At 25% market share, ethanol (E10) adds about 2 tons per day of VOC to the current inventory. If the ethanol market share were to increase from 25% to 100% (as assumed to be the case with Ca RFG or RFG), VOC permeation emissions would increase an additional 5.3 tons per day.

Results of Gasoline Analysis

The cumulative VOC and NOx benefits estimated in the study for the gasoline options are shown in Figures ES-1 and ES-2. Estimates are shown using two different models to predict exhaust emission changes - the EPA Complex Model, and the California Predictive Model. Results from the two models should not be averaged, they should instead be viewed as the range of likely benefits.

Figure ES-1. Net VOC Benefits in 2007 - All Sources
(tons per summer day)



<u>Notes for Figure ES-1</u>

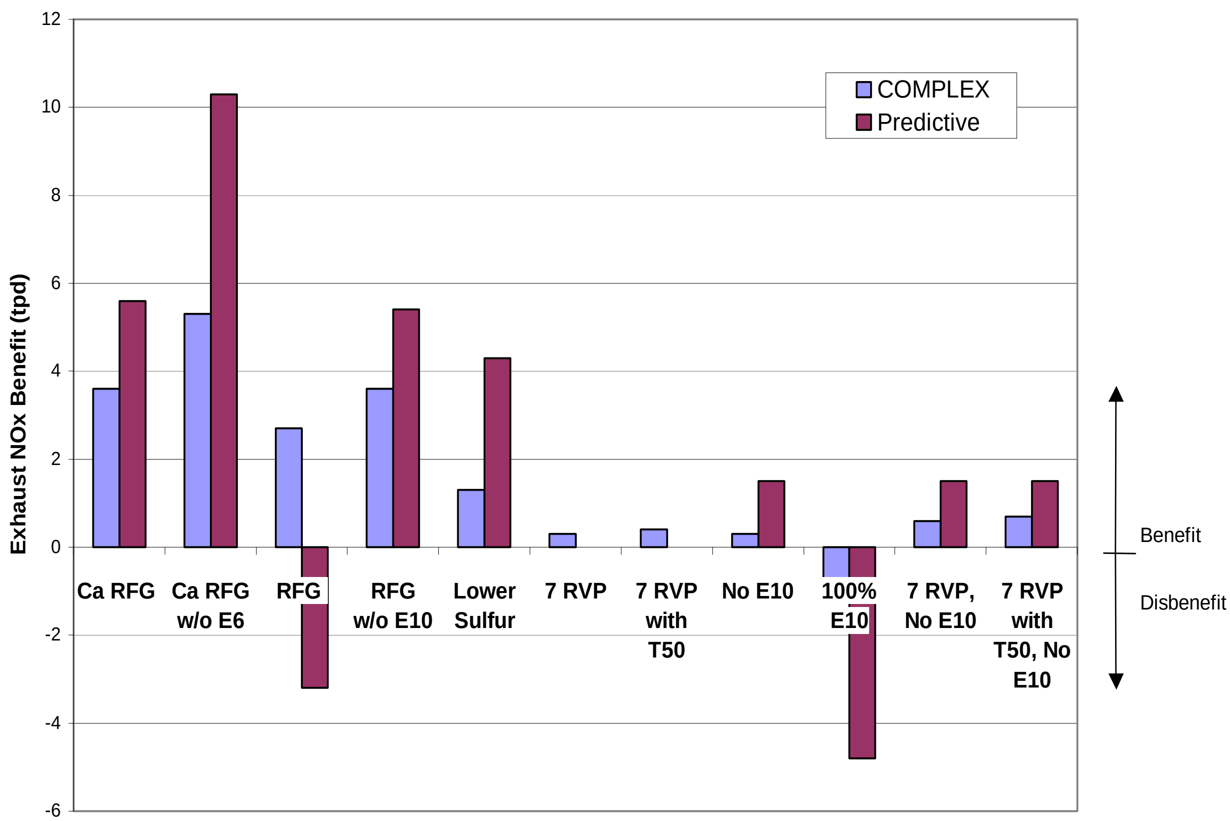
1. Includes all exhaust and evaporative effects, including ethanol permeation, where applicable.
2. Includes both on-road and off-road sources.
3. E6 and E10 refer to the volume percent of ethanol in the gasoline. E6 denotes a 6% ethanol concentration; E10 denotes a 10% concentration. 100% E10 denotes 100% market share of E10 fuel.
4. *7 RVP with T50* is a low volatility sensitivity case in which T50 is assumed to increase by 3°F as a result of the lower RVP.
5. The reduction benefit of lower volatility fuels is expected to be higher than shown above because the NONROAD model does not currently include hot soak and running losses, and these components would be reduced with lower volatility fuels.

Findings and Observations Regarding Gasoline VOC Emissions:

- California RFG and Federal RFG provide the greatest VOC reduction benefits.
- The benefits of both RFG programs are reduced when ethanol is used, due to the increase in permeation VOC emissions caused by ethanol.
- Lower volatility fuels (7 RVP and 7 RVP with T50) also provide significant reductions, roughly half the benefit of reformulated gasoline.
- If the T50 level of lower volatility (7 RVP) fuel increases, the Predictive Model indicates the overall VOC benefit will be reduced.
- If ethanol were not used at all in Southeast Michigan (No E10 option), VOC emissions would be lower due to the elimination of ethanol-induced permeation and the reduced evaporative emissions due to lower average volatilities (ethanol currently receives a 1.0 psi waiver).
- The benefits of 7 RVP can be added to the benefits of no ethanol. The benefits of the combined options are a little less than the reformulated gasoline options.

- Retaining the current gasoline program, and increasing the ethanol market share to 100% (100% E10 option) shows a significant VOC increase due to increased permeation.
- The VOC benefits shown in all the lower volatility options in Figure ES-1 (Ca RFG, RFG, 7 RVP, and 7 RVP with T50) are understated because EPA's NONROAD model does not currently include hot soak and running losses, which are sensitive to fuel volatility changes Emissions from portable containers would also be lower. These benefits are expected to be significant.

Figure ES-2. Net NOx Exhaust Benefits in 2007 - All Sources
(tons per summer day)



Note: Figure ES-2 includes both on-road and off-road sources.

Findings and Observations Regarding Gasoline NOx Emissions:

- Emission reduction benefits are highest for the two California RFG options.
- The Predictive Model estimates significantly greater NOx benefits than the Complex Model for the California RFG and Lower Sulfur options. In general, the Predictive Model is thought to provide better results as it uses more recent data on the impacts of sulfur on exhaust emissions.

- For Federal RFG, the Complex model predicts a NOx benefit, while the Predictive Model shows a disbenefit. While EPA and the California Air Resources Board both agree that ethanol produces a NOx disbenefit in 1988-1995 light duty vehicles, only the Predictive Model currently takes this into account. Therefore, it is generally believed to provide better NOx emissions estimates for fuels containing ethanol. It should be noted that the Predictive Model also assumes an ethanol-related disbenefit for 1996 and newer vehicles. As of the writing of this report, it is our understanding that EPA believes the data on these vehicles is not conclusive.
- Both the RFG without ethanol and lower sulfur options show sizeable NOx benefits.
- Lower volatility fuels (7 RVP & 7 RVP with T50) have little or no effect on NOx.
- For the No E10 option, i.e. no ethanol would be used in Michigan, the Predictive Model shows a small NOx benefit.
- For the 100% E10 option, i.e. all Southeast Michigan gasoline would be 10% ethanol, the Predictive Model shows a significant NOx disbenefit.

It should be noted that, while most of the gasoline options tested could not be implemented in combination with one another, the 7 RVP and lower sulfur options are not necessarily mutually exclusive. In this case, the VOC and NOx emission benefits would be additive. In addition, while the CaRFG and RFG estimates without ethanol show favorable emission reductions, both fuels are required to include ethanol at a minimum concentration. CaRFG is currently not available outside of California.

Carbon monoxide (CO) inventory changes for the various gasoline fuel options are shown in Table ES-2.

Table ES-2. Net CO Benefits - All Sources (tons per summer day)

Year	CaRFG	CaRFG w/o E6	RFG	RFG w/o E10	Low RVP, Low sulfur	100% E10	No E10
2007	125	-83	273	-83	0	265	-83
2010	122	-81	264	-81	0	257	-81
2015	123	-81	266	-81	0	260	-81
2020	128	-85	277	-85	0	272	-85

Notes for Table ES-2
1. Includes both on-road and off-road sources.
2. CO changes were estimated using EPA's MOBILE6.2 model, and adjusting the inputs for percent ethanol, ethanol concentration, RVP, and waiver status.

Findings and Observations Regarding Gasoline CO Emissions:

- Ca RFG, RFG, and 100% E10 fuel scenarios would significantly reduce both on-road and off-road CO emissions.
- If ethanol were not utilized in Michigan (No E10 option), CO emissions would increase by roughly 80 tons per day.

Gasoline sulfur also affects CO, but this analysis did not estimate the impact of changes in gasoline sulfur level on CO emissions due to the lack of analytical tools. Both

Ca RFG and the low sulfur fuel option would show an increase in CO benefits if this factor were included.

Findings and Observations Regarding Other Gasoline Pollutants

- California and Federal RFG, with or without ethanol, would provide significant toxic emission reduction benefits.
- Lower sulfur and lower RVP would provide some small toxic emissions benefits.
- California RFG and low sulfur fuel would provide some small exhaust PM2.5 benefits due to the reduction in sulfur levels from 30 ppm to about 10 ppm.

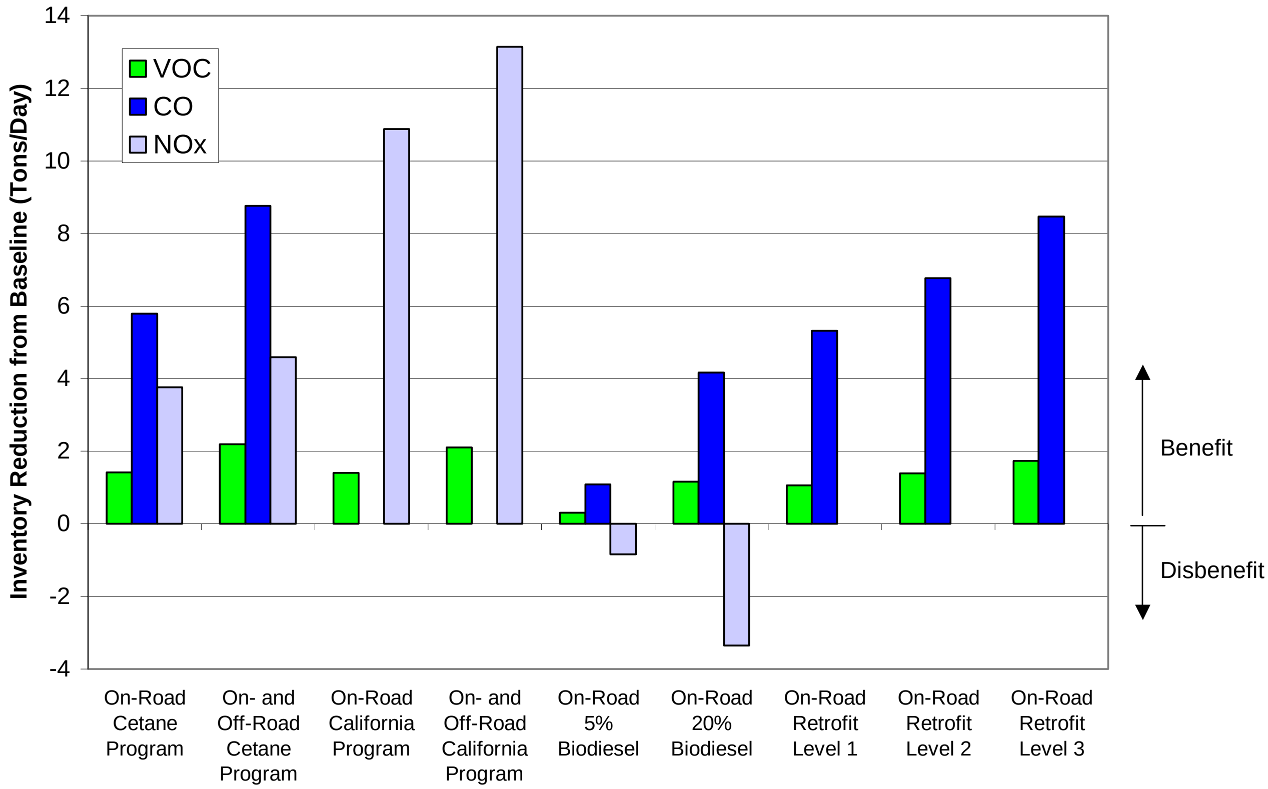
Results of Diesel Analysis

Figure ES-3 summarizes the 2007 VOC, CO and NOx emissions benefits from the different diesel programs.

Findings and Observations Regarding Diesel VOC, NOx and CO Emissions:

- As with gasoline, the emission reduction benefits of different diesel formulations vary significantly. The largest reductions come from California diesel, which yields over twice the NOx benefit of the high cetane option. However, California diesel is not manufactured outside of California, and the high cetane fuel studied is not manufactured or used anywhere in the U.S.
- VOC benefits range from 0.3 tons/day for the 5% biodiesel program to just over 2 tons/day for the cetane and California diesel programs that cover both on- and off-road diesel.
- NOx benefits range from a 3 ton per day increase for the 20% biodiesel program to roughly a 13 ton per day reduction estimated for the on- and off-road California diesel program.
- Biodiesel produces the least VOC and CO emissions benefit of all the diesel options and has a NOx disbenefit, which increases as the "bio" fraction increases.
- There are no measurable NOx benefits from diesel retrofit programs.
- None of the diesel options produce significant VOC emission reductions.

Figure ES-3. Summary of Inventory Benefits of Diesel Programs VOC, CO and NOx in 2007



Notes for Figure ES-3

1. Each program was assumed to achieve 100 percent implementation or coverage over the 7-county SEMCOG region. As such, all applicable diesel engines would operate under the specifics of each program.
2. No data or equations were provided by EPA for estimating CO benefits from California Diesel, therefore, CO impacts for this fuel were not modeled.
3. Because available data for off-road bio-diesel benefits is inconclusive and very few retrofit technologies have been approved for off-road use, off-road emissions benefits were not modeled for these programs.

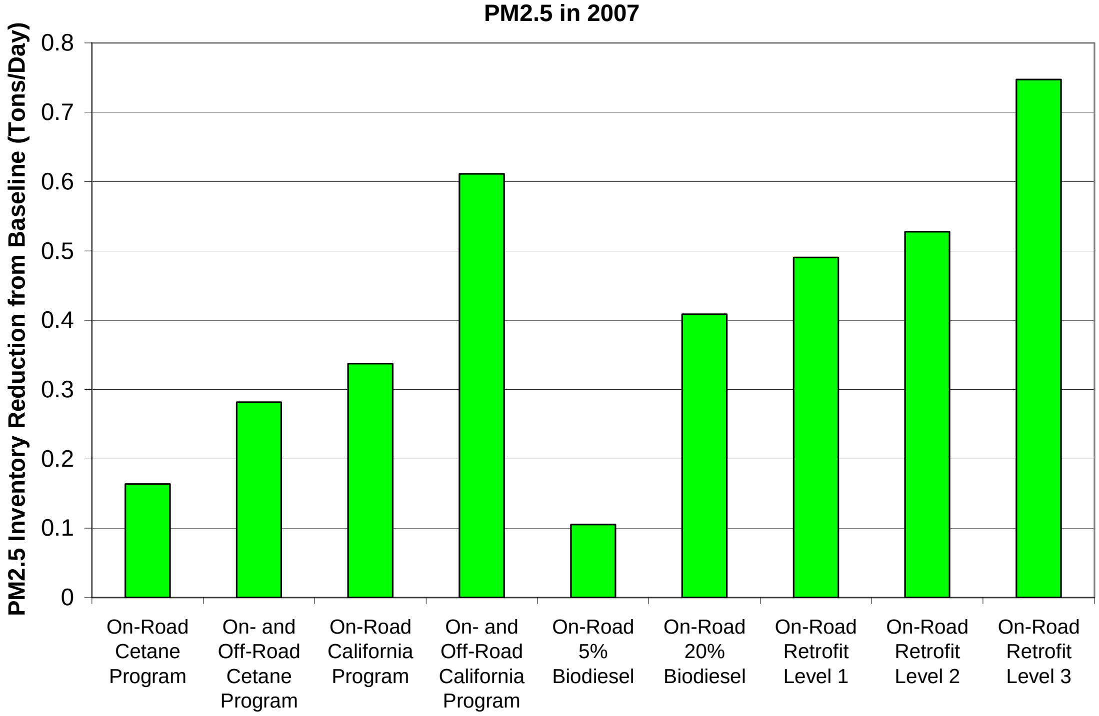
Findings and Observations Regarding Diesel PM2.5 Emissions:

Figure ES-4 summarizes the 2007 PM2.5 exhaust emissions benefits from the various diesel options. Benefits were estimated relative to the Baseline mobile source inventory, which for PM2.5 in 2007 is estimated at 9.4 tons/day for all diesel equipment and vehicles.

- As with NOx, the largest PM2.5 reduction comes from California diesel, which yields over twice the benefit of the high cetane option.
- Overall, benefits range from roughly 0.1 tons per day for the 5% biodiesel program to nearly 0.8 tons per day for the Level 3 diesel retrofit program.
- On a percentage basis, the PM2.5 benefits range from 2 to 11 percent of diesel emissions.

- The diesel retrofit options show a comparatively high PM2.5 benefit. However, these values assume 100% implementation on all vehicles operating in the region, while surveys indicate only 36% of truck activity in the region is from centrally-fueled, local fleets.

Figure ES-4. Summary of Inventory Benefits of Diesel Programs PM2.5 in 2007



<u>Notes for Figure ES-4</u>
1. For the purpose of this study, each program was assumed to achieve 100 percent implementation or coverage over the 7-county SEMCOG region. As such, all applicable diesel engines would operate under the specifics of each program.
2. Because available data for off-road bio-diesel benefits is inconclusive and very few retrofit technologies have been approved for off-road use, off-road emissions benefits were not modeled for these programs.

General Findings and Observations:

In addition to the specific findings and observations by pollutant and fuel, some other noteworthy results to be considered in policy discussions that might follow this report are listed below.

- Currently available tools for estimating benefits of different fuels have limitations and, in some cases, predict very different results. Nonetheless, through careful application of model inputs and cautious interpretation of model outputs, a good understanding of the range of impacts of different fuel configurations was achieved and is summarized in this report.

- The vast majority of emission reductions from mobile sources between 2002 and 2007 (40% in VOC and 40% in NOx) will result from the phasing-in of existing federal regulations, most notably, more stringent vehicle emission standards and reduced sulfur in both gasoline and diesel fuel. Potential emission reductions from the fuel strategies studied are relatively small when compared to the decrease in the mobile source inventory and will decrease with time beyond 2007 as the overall mobile source inventory decreases.
- Generally, the gasoline fuel options produce higher VOC benefits while diesel options can produce the highest NOx benefits and also decrease PM2.5 emissions.
- Different fuels produce a wide range of benefits, and in some cases disbenefits, for each of the pollutants evaluated. Therefore, the best fuel option, or combination of options, will depend on which pollutants need to be reduced, how much reduction is needed, what it will cost, and when it can be implemented. The data in this report should be combined with other information as part of the policy decision on which new fuels, if any, to select.

2.0 Introduction

On April 15, 2004, the EPA finalized its list of 8-hour ozone nonattainment areas. Eight counties in Southeast Michigan were designated as a "moderate" nonattainment area. Under EPA rules, moderate areas have until 2010 to attain the 8-hour ozone standard. Moderate areas must also implement a vehicle inspection program if they do not already have one, and reduce ozone precursors by 15%.

Subsequently, the Southeast Michigan Council of Governments (SEMCOG) and Michigan Department of Environmental Quality (MDEQ) requested a reclassification from EPA to a marginal area. Approval from EPA was obtained on September 15, 2004. Marginal areas do not have to implement vehicle inspection programs or implement a 15% reduction in emissions by 2010, but they must attain the ozone standard by 2007. SEMCOG's and MDEQ's request for a reclassification did not change their commitment to attain the standard, but it did give them additional flexibility on meeting the standard. [1]

To ensure that the Southeast Michigan area attains the ozone standard as soon as possible, the SEMCOG has been studying ways to reduce ozone precursors. As a part of this effort, SEMCOG initiated a study of potential changes in gasoline and diesel fuel specifications. SEMCOG formed a stakeholder group consisting of representatives with expertise from the oil industry, automobile industry, the Michigan Department of Agriculture and the Michigan Department of Environmental Quality to provide guidance to the study. SEMCOG contracted with Air Improvement Resource, Inc. (AIR) to evaluate the emission reductions of the fuel changes.

Currently, the Southeast Michigan area has a low RVP requirement for gasoline, which stipulates that gasoline volatility in the summer cannot exceed 7.8 psi. Ethanol blends have a 1.0 psi waiver. Recent surveys by the Alliance of Automobile Manufacturers indicate that ethanol has about a 25% market share in Southeast Michigan.

Gasoline sulfur levels in Southeast Michigan in the 2001-2002 period were about 421 ppm (on a grade-weighted basis), which is significantly greater than the 259 ppm used by EPA in the MOBILE6 model. [2] The Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements promulgated by EPA will lower this sulfur level to 30 ppm over the next few years. Also, the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Requirements for 2007 will significantly reduce in-use diesel sulfur levels, and the 2010 rule for Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel will reduce off-road diesel sulfur levels.

In order to focus the study, the stakeholder group agreed to evaluate the emission reductions benefits of the following list of fuels and related controls:

Gasoline

- California reformulated gasoline (Ca RFG)

- Federal reformulated gasoline (RFG)
- Lower sulfur gasoline (10 ppm average)
- Lower volatility gasoline (limit of 7.0 psi Reid vapor pressure (RVP))
- A range of ethanol (E10) market penetrations (0% and 100% E10)

Diesel

- California (CARB) diesel
- High cetane diesel
- Biodiesel (5% and 20%, or B5 and B20)
- In-use diesel engine PM retrofits

The stakeholders desired that the study be as comprehensive as possible, which, in some cases, included assessments of the same fuel using different modeling tools. These include EPA's MOBILE6.2 model, EPA's Complex model, EPA's NONROAD model, and the California Air Resources Board's Predictive Model. This would allow for a more complete perspective for evaluating results in light of each model's strengths and weaknesses.

SEMCOG and MDEQ have separate efforts underway to evaluate other emission control programs that would help it to attain the 8-hour ozone standard, such as vehicle Inspection and Maintenance programs and other control programs. This report only focuses on the fuel options.

This report is organized into the following sections. The Background section reviews the existing regulatory programs that will change fuel composition in the Southeast Michigan area, and describes the capabilities and limitations of the various models that can be used to evaluate fuel changes. The Methods section discusses implementation dates for the potential control programs, evaluation years, baseline and control fuel properties, and the methods used to evaluate exhaust and evaporative emissions changes. The Results section discusses emission changes for the various potential control options, and the Discussion section summarizes the results and discusses the implications of the results for Southeast Michigan and other areas of the country.

3.0 Background

This section summarizes Michigan's current program limiting gasoline volatility in the summertime, as well as information on other federal regulations that will have an effect on gasoline and diesel fuel specification over the next 6-7 years. The section that follows discusses the emission models MOBILE6.2 and NONROAD, regarding inputs and outputs, capabilities and concerns. The last section discusses the California Predictive Model and EPA Complex model for evaluating the exhaust emission effects of various reformulated gasolines.

3.1 Michigan's Volatility Control Program

Michigan's low volatility fuel program, which started in 1995, extends to seven southeastern Michigan counties – Wayne, Oakland, Macomb, Washtenaw, Livingston, St.Clair, and Monroe. [3] Gasoline fuel volatility is limited to 7.8 psi RVP from June 1st to September 15th. The program includes a 1.0 psi waiver for ethanol blends, so the volatility limit for ethanol blends is 8.8 psi. The rule exempts gasoline dispensed at marinas, test tracks, and applications for agricultural purposes.

3.2 Other Regulations Affecting Michigan Fuel Quality

Several other gasoline and diesel fuel regulations have been adopted by the EPA that affect emissions in southeast Michigan.

First, the Tier II/Gasoline Sulfur Requirements started reducing gasoline sulfur levels in 2004. [4] The low sulfur requirements are being phased-in over 3 years from 2004-2006. In 2004 and 2005, refiners must meet corporate pool averages of 120 ppm and 90 ppm, respectively. By 2006, the average for each refinery must be 30 ppm.

Along with the low sulfur fuel, EPA implemented much more stringent Tier II exhaust standards for cars and light trucks. The lower sulfur fuel not only enables these more stringent standards to be met, it lowers HC, CO, and NOx emissions from all catalytic converter-equipped vehicles on the road.

Second, the low sulfur diesel rule adopted by EPA requires on-road diesel sulfur levels to be reduced to 15 ppm by June 1, 2006. [5]

Third, the recently promulgated nonroad diesel engine and fuel standards require the sulfur level of nonroad diesel for nonroad engines, marine, and locomotives to be reduced to a maximum of 500 ppm by June 1, 2007. This is further reduced for nonroad engines to 15 ppm by June 1, 2010, and for marine and locomotives to 15 ppm by June 1, 2012. [6]

In addition to the above federal regulations implemented by the EPA, Michigan banned the fuel additive MTBE in response to concerns over groundwater contamination from leaking underground storage tanks and atmospheric deposition. While Michigan does not currently require reformulated gasoline (which must contain nominally 2.0 wt % oxygen, according to the 1990 Clean Air Act Amendments), oxygenates are used in Michigan by refiners – around 25% of the fuel sold in Southeast Michigan currently contains ethanol. The MTBE ban was implemented in 2004. [7]

3.3 Recent Developments Regarding Emission Changes Due to Use of Ethanol

It is generally known that ethanol in gasoline reduces exhaust hydrocarbon and carbon monoxide emissions from on-road and off-road vehicles and equipment, especially on older on-road vehicles that may have a tendency to run "rich", and all off-road vehicles. The mechanism for reduced emissions is the additional oxygen supplied by the ethanol, which improves combustion. There is some debate as to whether ethanol reduces emissions from 1996 and later on-road vehicles with advanced fuel controls and 3-way catalysts with adaptive memory, for this reason, the Coordinating Research Council (CRC) is conducting a testing program to evaluate ethanol effects on these low emission vehicles (LEVs). [8] The effect of ethanol on exhaust HC and CO emissions is built-into the existing EPA emissions models, MOBILE6 (on-road) and NONROAD (all non-road sources).

It is also generally known that ethanol increases the volatility of gasoline. Many states (including Michigan) grant a 1 psi waiver for ethanol blends. This allows refiners to blend ethanol with available gasoline that is also marketed without ethanol. This reduces the cost of ethanol blends compared to the cost if volatility were held constant. Higher volatility gasolines, however, produce more evaporative emissions and exhaust emissions from on-road and non-road sources.

Even if a waiver is not granted for ethanol and it has the same volatility as non-ethanol gasoline, when the two are mixed in a vehicle's fuel tank (for example, when a vehicle owner gets a full tank of non-ethanol gasoline, and then fills up the next time from 1/3 full with ethanol gasoline of the same volatility), the volatility of the combined gasolines can be higher than the two gasolines before they were combined, thereby again increasing evaporative emissions. This effect is called the commingling effect. Both the waiver effect and the commingling effect are included in estimating evaporative emissions in the MOBILE6 model. Neither effect is included in the NONROAD model, but EPA is revising the NONROAD model to update evaporative emissions for nonroad sources, to include these effects.

There are two relatively recent phenomenon related to ethanol, however, that have not been included in the MOBILE6 and NONROAD models, and are incorporated into this study. First, in 2001, California requested a waiver from the federal oxygenate mandate in the Clean Air Act. The grounds for the wavier request were, among other items that ethanol increases NOx emissions from 1986 and later light duty vehicles, and NOx reductions are needed in California to attain the ozone and fine PM ambient air quality standards. The wavier was eventually denied by the EPA. But EPA did indicate that it agreed that ethanol increases NOx emissions on 1985-1995 vehicles. However, EPA was not convinced that NOx emissions increase on ethanol blends for 1996 and later vehicles.

The second relatively recent issue concerns permeation emissions, which EPA defines as "evaporative VOC emissions that escape through soft fuel system components (such as hoses and seals), and that are associated with the use of ethanol in gasoline." [9] A recently released CRC report on the permeation effects of ethanol on on-road vehicles indicates that ethanol blends increase permeation emissions of volatile organic compounds (VOCs). [10] These issues are discussed in more detail further below.

3.3.1 Ethanol's Effect on NOx Emissions

California made a number of submittals in 1999 and 2000 in support of a request for a waiver of the reformulated gasoline oxygen content requirement for California covered areas. The waiver was eventually denied by the EPA in 2001. [9]

As EPA indicated in its Technical Support Document (TSD) analyzing the various CARB submissions, "CARB's Predictive model shows that NOx emissions increase as a function of oxygen in the fuel, which…is CARB's main argument in support to its claim that the oxygen requirment interfered with or prevented attainment of the NAAQS for ozone and particualte matter."

As a part of its analysis of the waiver request, EPA throroughly evaluated CARB's Predictive Model, and the underlying data for 1988 and later vehicles. In reviewing the underlying data, EPA determined that there was not sufficient evidence for the 1996 and later vehicles to conclude that ethanol increased NOx emissions. However, EPA did conclude that ethanol increased NOx emissions on 1988-1995 vehicles by 3 to 5 percent, depending on which statistical model for these vehicles was utilized. EPA concluded that the NOx effect it estimated for 1988-1995 vehicles was greater than the effect that CARB estimated for these vehicles.

While EPA agreed with the California Air Resources Board (CARB) that there was a NOx increase for these vehicles, it denied the waiver request based on the evaluation of many factors, including the NOx effect, commingling effect, CARB's estimate of the effect of ethanol on VOC and NOx emissions, and other factors. More recently, however, CARB has submitted an updated waiver request, which was still under review by EPA at the time this report was prepared (December, 2004).

Even though CARB and EPA agree that ethanol increases NOx in 1988-1995 vehicles, there is disagreement over the effects of ethanol on 1996 and later vehicles. This presented a problem for this study as AIR was unable to include the NOx effect by simply applying EPA's MOBILE model. All of the other effects of ethanol (except the permeation effect discussed below) are included in MOBILE6.2.

To address this issue, the stakeholder group requested an evaluation of exhaust HC and NOx with both the EPA Complex Model and the California Predictive Model.

Both models include effects of oxygenates on NOx emissions; the Complex Model shows a slight decrease of NOx with ethanol while the Preeictive Model shows an increase of NOx with ethanol. This allowed for evaluating a range of NOx effects. But, readers are cautioned that when the NOx effects are evaluated using the Predictive Model, the results in this study could overestimate the NOx effect, especially in the outlying projection years when 1996 and later vehicle predominate.

3.3.2 Effects of Ethanol Blends on Permeation Emissions

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. [10]

The testing program revealed that ethanol increases permeation emissions from on-road passenger cars and light duty trucks an average of 1.1 to 1.4 grams per day per vehicle depending on whether the ethanol fuel was compared to an MTBE fuel or a non-oxygenated fuel, under the test conditions. The testing also found that this increase in 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.

Recognizing that the CRC data and report would be released, and desiring to determine the inventory impacts of ethanol, the American Petroleum Institute 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, the New York/New Jersey/Connecticut area. [11]

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 in 2003. This study of fuel options in Southeast Michigan is also evaluating a number of different gasoline options that utilize ethanol. The permeation effects of ethanol developed in this study are consistent with those developed by AIR, Inc. for API.

3.4 Emission Models

The two models used in the Southeast Michigan area to develop mobile source emission inventories are MOBILE6 and NONROAD. The following sections discuss the capabilities and limitations of these models in performing this study.

3.4.1 MOBILE6

3.4.1.1 Gasoline Programs

The MOBILE6 model can be used to evaluate the effects of federal reformulated gasoline, lower volatility gasoline, and various ethanol market penetrations. There are five commands that are utilized to select MOBILE6 fuel options:

- The "Fuel Program" command designates the fuel sulfur level of gasoline after calendar year 2000, and whether RFG use should be assumed
- The "Sulfur Content" command allows the user to enter alternative sulfur content of gasoline that overrides the MOBILE6 default of 300 ppm for years prior to 2000.
- The "Oxygenated Fuels" command allows modeling of the effects of oxygenated fuels on exhaust and evaporative emissions
- The "Fuel RVP" command allows the input of local fuel volatility in RVP.
- The "Season" command allows users to specify winter or summer RFG, independent of evaluation month

The Fuel Program, Oxygenated Fuels, and Fuel RVP commands can be used in this study to assist in the evaluation of the benefits of RFG, ethanol, and volatility controls. Further details on the capabilities of MOBILE6 with respect to evaluating the gasoline options for this study are discussed below.

California reformulated gasoline – California's reformulated gasoline specifications include modifications to volatility, sulfur, T50, T90, benzene, aromatics, olefins, and oxygen content. While the MOBILE6 model uses many of these inputs to determine toxics emissions, it does not use them for establishing VOC or NOx emissions. Therefore, other techniques are needed to determine the benefits of California reformulated gasoline.

Federal reformulated gasoline – The model is capable of estimating the benefits of federal reformulated gasoline, as this is one of the input options. However, the model has not been updated to evaluate the effects of ethanol on NOx emissions, nor has it been updated to evaluate the effects of ethanol on permeation HC emissions. These effects need to be included to obtain a realistic picture of the benefits of some of the options which include the use of ethanol.

Lower sulfur gasoline – While sulfur is an input to the model, the model does not estimate any change in emissions for sulfur levels below 30 ppm, even though the available data indicate emissions do decrease below 30 ppm. Thus, other techniques need to be applied to estimate this benefit.

Lower volatility gasoline – The model includes an input for fuel volatility in psi, and the model corrects both exhaust and evaporative emissions for lower volatility fuel.

Ethanol effects – The model includes inputs for both market penetration and concentrations of oxygenates, including ethanol. However, like the RFG effects, the model does not evaluate the effects of ethanol on NOx, nor ethanol on permeation VOC emissions.

Based on the above, AIR concluded that MOBILE6 could be used to evaluate the hot soak, diurnal, and running loss differences due to the above fuel options. However, AIR concluded that other models and techniques would be needed to evaluate exhaust emission changes and permeation evaporative effects.

3.4.1.2 Diesel fuel options

MOBILE6 includes an input for fuel sulfur, but does not allow the user to evaluate California diesel, biodiesel, or higher cetane levels. Consequently, other techniques and models must be used to evaluate these fuel changes. Also, the model does not provide inputs for evaluating the effects of exhaust PM retrofits, so other techniques must be used here as well.

3.4.2 NONROAD

The NONROAD model estimates emissions for all gasoline and diesel nonroad sources. There are many different sources here, including lawn and garden equipment, construction, agriculture, recreational vehicles, recreational marine, etc.

For evaporative emissions, the current model only includes diurnal and crankcase emissions, and ignores hot soak, running loss, and permeation emissions. For this reason, the VOC benefits calculated for all the lower volatility fuel options in this study (Ca RFG, RFG, 7 RVP, and 7 RVP with T50) are less than would be expected if all evaporative emissions were taken into account. EPA is currently updating the model to include these other evaporative components, and a new release of the NONROAD model is expected sometime in 2005. However, MDEQ utilizes the current NONROAD model when estimating emissions from NONROAD sources.

NONROAD includes input for ethanol market share and concentration, and adjusts nonroad gasoline exhaust HC, CO, and NOx emissions for the ethanol effects. The model does adjust the existing diurnal emissions for changes in fuel volatility. The model does not include the effects of ethanol on permeation for off-road sources, as this is a very new issue that needs be considered.

One of the sources not included by the NONROAD model is portable fuel containers used to refuel nonroad gasoline sources, such as lawnmowers. Most portable fuel containers are plastic (high-density polyethylene, or HDPE). In fact, California estimates that about 75% of portable containers statewide are plastic. [11] These sources are considered area sources, rather than mobile sources, by EPA. Area source inventories are estimated by MDEQ, so portable container emissions would be included in that inventory. However, since this study is evaluating fuel changes, it is important to include portable containers in the overall analysis of fuel impacts.

3.5 Reformulated Gasoline Models

The discussions above reveal that MOBILE6 alone is not capable of evaluating the various gasoline changes on exhaust emissions from gasoline sources. Two other models are available which have a capability to do this – the EPA Complex model, and the California Air Resources Board Predictive Model. These models are typically used by oil companies and refiners to determine whether the gasoline they are manufacturing meets the reformulated gasoline requirements. However, parts of the EPA Complex model are incorporated in the MOBILE6 model to estimate toxic species. Also, the Predictive Model results are used by the CARB to estimate the benefits of Phase 3 of the California reformulated gasoline. So, the agencies have already firmly established the precedence of linking these models with their inventory models.

The Complex and Predictive models can be used in conjunction with the MOBILE6.2 model to develop a range of exhaust emissions benefits for the various gasoline options. They are briefly discussed below.

3.5.1 Complex Model

EPA's Phase 1 RFG requirements took effect in 1995, and the Phase 2 RFG requirements took effect in calendar year 2000. The Phase 2 RFG program requires VOC emissions in affected northern U.S. areas to be reduced by 27.4%, NOx by 6.8%, and toxics by 21.5%. These performance requirements are estimated with the EPA Complex model, using a reference gasoline called Clean Air Act (CAA) baseline gasoline. In addition, there are anti-dumping provisions that prevent gasoline in non-RFG areas from having higher emissions. [12]

In addition to the performance requirements above, the March 28, 2001 Toxics rules established an anti-backsliding program for conventional and RFG areas that started in 2002. In this program, total toxics as estimated with the Complex model cannot exceed the 1998-2000 baseline performance on a refinery basis. [13]

Oil companies use the Complex model to ensure that the gasoline they are providing meets the above performance and anti-backsliding requirements. The Complex model was required by the 1990 CAA to be built on the emissions response of Tier 0 vehicles (pre-1996 model years), tested on many different fuels. The model estimates the VOC, NOx, and toxics emission changes (not CO) for these vehicles for any gasoline, versus the Clean Air Act baseline gasoline. The following fuel parameters are inputs to the Complex Model:

- Fuel volatility (RVP in psi)
- Sulfur content (in ppm)
- E200 (percent of fuel evaporated at 200 ºF)
- E300 (percent of fuel evaporated at 300 ºF)
- Aromatics content (in volume %)
- Olefin content (volume %)
- Benzene content (volume %)

The major drawback to the current Complex model is that it does not include any data on 1996 and later vehicles, including Tier 1 vehicles or Low Emission Vehicles (LEVs). Tier 1 vehicles were introduced starting in 1994, the LEV vehicles were implemented in Michigan with model year 2001, and now Tier 2 vehicles are being introduced this year (2004). The Tier 1, LEV and Tier 2 vehicles will be the predominant vehicles in the time period of this study.

There are additional test data that could be incorporated into the model. For example, in 1998 and 1999, CRC performed testing of LEVs and their response to fuel sulfur level. These data were incorporated into the CARB Predictive Model. Nonetheless, since the Complex model is used to estimate the benefits of various fuel formulations as compared to the RFG performance specifications, it will also be used in this study to provide one estimate of the benefits of the various gasoline control cases. In utilizing the Complex model for this purpose, we are assuming that the percentage change in exhaust VOC, NOx, and toxics emissions for different fuel parameters for newer technology vehicles are the same as for Tier 0 vehicles.

3.5.2 CARB Predictive Model

The Phase 3 CARB Predictive Model is the CARB's counterpart to the EPA Complex model. It estimates VOC, NOx, and potency-weighted toxics emission changes (again, not CO) as compared to the Phase 3 CARB reformulated gasoline. [14] Inputs to the model are the same as the Complex model, except for the distillation parameters. For example, instead of E200 and E300, the corresponding Predictive Model inputs are T50 and T90. T50 is the temperature (usually in ºF) at which 50% of the fuel is evaporated, and T90 is the temperature at which 90% of the fuel has evaporated. A higher T50 means the fuel is a little "heavier", because a higher temperature was required to evaporate 50% of the fuel. T50 and E200 move opposite of each other. A higher T50 implies a lower E200. If a heavier fuel raises the T50 temperature, it also lowers the percent of fuel evaporated at the fixed temperature of 200ºF. EPA's Complex model contains equations for converting T50 and T90 into E200 and E300, and vice versa. These equations have been used in this study to convert E200 and E300 values to T50 and T90 values for use in the Predictive Model.

Unlike the Complex model, the Predictive Model is not tied to one group of vehicles. CARB has updated the Predictive Model as new data has become available. CARB also made major changes in the statistical techniques used to analyze all the data, for example, the CARB Predictive Model uses a "mixed" statistical model, while the EPA Complex model uses "fixed" statistical techniques. [9] EPA has indicated that if it were doing the Complex model now, that it would use a mixed statistical approach.

The Predictive Model estimates fuel responses for basically three different groups of vehicles – Tech 3 vehicles (pre-1988), Tech 4 vehicles (1988-95), and Tech 5 vehicles (1996+). It weights these responses together with their calendar year 2005 vehicle miles traveled fractions, producing emission changes that are for the 2005 California fleet of vehicles on the road.

Although there are many differences between the Predictive Model and the Complex model, one other difference germane to this study is that it does estimate that NOx increases with increasing ethanol concentration. The model estimates that emissions of both Tech 4 and Tech 5 vehicles increase with increasing ethanol concentration. This is discussed further in the next section.

4.0 Methods

This section describes the methods used to estimate emission changes due to the various fuel changes. Methods used to develop the gasoline emission impacts are discussed first, followed by the methods used for diesel fuel and retrofit impacts.

4.1 Gasoline Option Methods

4.1.1 Description of Options

As indicated in the Introduction, the following options were evaluated:

- California reformulated gasoline
- Federal reformulated gasoline
- Lower sulfur gasoline
- Lower volatility gasoline
- A range of ethanol concentrations

These options are discussed in more detail below.

4.1.1.1 California Reformulated Gasoline

Phase 3 of California's reformulated gasoline regulations were adopted by the Air Resources Board in 1999, with implementation occurring in 2003/2004. [14] The Phase 3 specifications are shown in Table 1. Oil companies can choose to certify according to the flat limits or averaging limits, but fuels cannot be produced with parameters above the cap limits.

Table 1. California Phase 3 Requirements

Parameter	Flat Limit	Averaging Limit	Cap Limit
Volatility (psi)	6.90/7.00	None	7.20
Suflur (ppm)	20	15	30
Benzene (vol %)	0.8	0.70	1.10
Aromatics (vol %)	25.0	22.0	35.0
Olefins (vol %)	6.0	4.0	10.0
T50 (°F)	213	203	220
T90 (°F)	305	295	330
Oxygen content (wt %)	1.8-2.2	None	1.8-3.5

While some other states have opted into the California vehicle standards, no state has opted into California reformulated gasoline. The reasons for this are beyond the scope of this study. The state of Arizona, however, did adopt specifications that allowed either Federal reformulated gasoline or California reformulated gasoline to be sold in Phoenix. However, Arizona was prevented from adopting the toxics portion of the California reformulated gasoline specifications. Benzene has the largest influence on the potency-weighted toxics in the Predictive model. Therefore, this study will examine a California reformulated gasoline without a benzene reduction. This fuel is assumed to have ethanol at 2.0 wt % (5.7% by volume), and the market penetration of ethanol is assumed to be 100% in this case.

The CAA required nine areas in the U.S. to have reformulated gasoline, and allowed other areas to "opt-in" to RFG. Southeast Michigan was not one of the 9 areas, nor did it opt-in to RFG. The CAA also required reformulated gasoline to contain a minimum oxygen content of 2% by weight. Because Southeast Michigan was not required to have RFG, it could conceivably adopt the California RFG specifications related to NOx and VOC reduction, without the oxygen requirement. While oxygen would not be required, it would probably be used by some gasoline marketers. Therefore, two California RFG options are investigated in this study. One scenario examines 100% E6 market share, while the other assumes 0% ethanol. The two California RFG options are referred to as:

- CA RFG
- CA RFG w/o E6

4.1.1.2 Federal Reformulated Gasoline

The Federal RFG rules require VOC emissions in Northern U.S. ozone non-attainment cities to be reduced by 27.4%, NOx by 6.8%, and toxics by 21.5% from the CAA baseline gasoline. Also, RFG must contain 2.0 wt % oxygen. Oil companies and refiners use the EPA Complex model to determine if their recipe meets these specifications. They can choose between reducing fuel volatility, sulfur content, aromatics, etc., as a means of meeting the performance goals.

Phase 2 of the RFG requirements were implemented in calendar year 2000, so oil companies and refiners improved their gasoline formulations to meet these requirements. In 2001, however, EPA also adopted the Tier 2/Low Sulfur rules, which reduce gasoline sulfur levels nationwide to 30 ppm average by 2006. Thus, gasoline providers to RFG areas will also have to reduce sulfur levels to 30 ppm, if they have not already as the result of RFG. Implementation of the low sulfur requirements could result in overperformance of the required RFG VOC, NOx, and toxics percent reductions, consequently, RFG formulations may change in RFG areas once the low sulfur rule is fully implemented.

It is important to realize that implementation of RFG in Michigan will not achieve the performance benefits of 27.4% and 6.8% for VOC and NOx, respectively. The reason for this is that the Michigan baseline gasoline in 2006 is different from Clean Air Act baseline gasoline, both because Michigan gasoline is not like the national average gasoline, and also because sulfur controls have been fully implemented by 2006, and the Clean Air Act baseline gasoline assumes sulfur levels are 339 ppm. These issues are discussed further in section 4.1.6.3.

Also, similar to the California RFG options, Michigan could conceivably implement RFG-like requirements for NOx and VOC redutions without the oxygen requirement. This study will therefore examine two cases – RFG with E10, and RFG without E10.

4.1.1.3 Lower sulfur gasoline

Existing federal gasoline regulations will reduce sulfur levels to around 30 ppm. The California Phase 3 requirement reduced sulfur to 20 ppm, indicating that additional benefit is available to further reducing sulfur levels. This study examines the benefits a currently undefined requirement that would result in a sulfur level of 10 ppm.[1] Under this scenario, ethanol market share,concentration, and the existence of a 1 psi waiver for ethanol were assumed to remain the same as the baseline.

4.1.1.4 Lower volatility gasoline

Southeast Michigan's summertime volatility limit is currently 7.8 psi. Other areas of the country have implemented summertime volatility controls as low as 7.0 psi. For example, California's Phase 3 RFG RVP limit is 7.0 psi. Also, Atlanta and St. Louis have reduced fuel volatility to 7.0 psi. Therefore, this study will also examine lowering the volatility limit of summertime gasoline to 7.0 psi. This option will assume that ethanol market share, concentration, and the existence of a 1 psi waiver for ethanol is the same as the baseline.

4.1.1.5 Range of ethanol market shares

The Alliance of Automobile Manufacturers' survey data, which is collected randomly at major service stations, indicates an ethanol market share of about 25% in Southeast Michigan, i.e., about 25% of gasoline contains ethanol. This study will also examine the impacts of two extreme ethanol limits – no ethanol (0%) and ethanol in every gallon of gasoline (100%).

These options are being evaluated because at least one other state (Minnesota) that is not required to have RFG has implemented an ethanol mandate. Questions may also arise in Michigan with respect to the benefits of different levels of ethanol, in comparison with the other options. [15] This scenario will assume that the 100% E10 market share continues to receive the 1 psi waiver.

Table 2 summarizes the ethanol market shares assumed under the different gasoline options.

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[1] Since this is an emission benefit study, there was not a compelling need to define the requirement that would result in a 10 ppm average – this can be done by other organizations if this is viewed as a viable option from an emission benefit and cost-effectiveness perspective.

Table 2. Ethanol Market Share Assumed for Fuel Scenarios		
Option	Ethanol Market Share	Waiver?
Baseline	25%	Yes
Ca RFG	100%	No
Ca RFG w/o E6	0%	No
RFG	100%	No
RFG w/o E10	0%	No
Lower sulfur	25%	Yes
Lower volatility	25%	Yes
0% E10	0%	No
100% E10	100%	Yes

4.1.2 Assumed Implementation Date of Gasoline Options

Moderate 8-hour ozone nonattainment areas must attain by 2010, and marginal 8-hour ozone nonattainment areas must attain by 2007. Since the time of this study is late 2004, it was decided to assume that the potential diesel and gasoline control measures could be put into place by the summer of 2006. This assumption implies nothing about the lead-time that the refining industry may need to implement these measures. Rather, the date was chosen to allow flexibility in examining the various options and a common basis for comparing results. The assumption allows SEMCOG to evaluate any implementation date. Since we are also evaluating baseline emissions, if a later date is chosen for implementation of a control program, for example, 2009, one only needs to assume that the baseline emissions are in effect though 2008, and that the control emissions start in 2009 (instead of 2006). The 2006 implementation date is assumed for all gasoline control programs.

EPA's final rule on federal reformulated gasoline Phase II performance standards was issued February 16, 1994 for implementation on January 1, 2000. California's final rule on its reformulated gasoline standards for Phase II was issued in the fall of 1991 for implementation in the spring of 1996. The petroleum industry recommends a minimum four year implementation lead time from the date of final regulation for fuels with stringent standards, such as federal and California reformulated gasolines and California diesel.

4.1.3 Pollutants Considered and Evaluation Years

This study examines exhaust VOC, evaporative VOC, permeation VOC, CO, NOx, and PM, from on-road and off-road gasoline and diesel vehicles, off-road equipment, and portable fuel containers. Portable fuel containers are not in either of the EPA models, but have been included to allow a complete evaluation of ethanol's effect on permeation VOC emissions.

The EPA requires that modeling that is performed for estimating attainment of the 8-hour standard utilize a base year of 2002. Consequently, 2002 is the base year for this study. Since 2007 is the required attainment date for a marginal area, emission inventories will also be estimated for 2007. To determine impacts beyond 2007, inventories are estimated for 2010, 2015 and 2020.

4.1.4 Overview of Gasoline Option Methods

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 either Complex or Predictive Model
Evaporative effect from onroad vehicles = change in evaporative emissions as estimated by MOBILE6.2 directly
Peremeation 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

The following sections discuss specific methods used to estimate exhaust and non-permeation evaporative emissions from on-road vehicles and off-road equipment. This is followed by a section which discusses the permeation effects on all three sources.

4.1.4.1 On-Road Vehicle Exhaust and Evaporative Methods

Baseline exhaust and evaporative emissions for on-road vehicles are estimated with the MOBILE6.2 model.

For the various control cases, the HC and NOx exhaust emission reductions are estimated by applying a factor to the baseline gasoline exhaust inventories, where the factor is developed from utilizing either the EPA Complex model or the CARB Predictive Model and applied to the SEMCOG baseline inventories. This is shown below.

Reduction = Baseline Inventory * Fuel Factor

Fuel Factor = % change in emissions with [Complex or Predictive] relative to the SEMCOG baseline

In estimating the above Fuel Factor, relevant fuel properties needed by both the Complex and Predictive Models are determined for the baseline case and for the various control options. These inputs are shown in Table 3. The fuel properties for baseline and control cases are developed in section 4.1.6.

Table 3. Fuel Property Input Required for Complex and Predictive Models

Complex	Predictive
Volatility (RVP, psi)	Volatility (RVP, psi)
E200 (%)	T50 (F)
E300 (%)	T90 (F)
Aromatics (vol %)	Aromatics (vol %)
Sulfur (ppm)	Sulfur (ppm)
Benzene (vol %)	Benzene (vol %)
Olefins (vol %)	Olefins (vol %)
Oxygen (wt %)	Oxygen (wt%)

It is important to note that both models estimate an emission change from a particular reference fuel, and in both cases the reference fuel is not the SEMCOG baseline fuel. In the case of the Complex model, the reference fuel is known as Clean Air Act baseline fuel. In the Phase 3 Predictive Model, the baseline fuel is the actual Phase 3 specification. Consequently, in order to use these models, the SEMCOG baseline fuel characteristics are input into both models, as well as the control fuel characteristics. Then, the relative changes in emissions of the control fuels as compared to the reference fuel are compared to the relative change in emissions of the SEMCOG baseline fuel compared to the reference fuel. The algebraic method for accomplishing this is as follows:

Fuel Factor = (% Reduction of Control Fuel Relative to Reference Fuel - % Reduction of SEMCOG Baseline Relative to Reference Fuel)/(1+ % Reduction of SEMCOG Baseline Relative to Reference Fuel)

An example of this calculation is shown in Attachment 1.

Evaporative emissions are very sensitive to fuel volatility (as measured by RVP), ethanol market share, and temperature. The MOBILE6.2 model includes fuel volatility and temperature as inputs, so the MOBILE6.2 model is used to evaluate changes for all of the control cases for evaporative emissions, except for the permeation effects of ethanol. The inputs needed to estimate these evaporative emissions for the various control cases are base fuel volatility, ethanol market share, and the waiver status. These are developed in Section 4.1.6.

4.1.4.2 Off-road - Exhaust and Evaporative

Emissions from these sources are estimated by SEMCOG with EPA's NONROAD model. For evaporative emissions, the current version of the NONROAD model only includes diurnal and crankcase emissions, but the diurnal emissions are corrected for fuel volatility. The exhaust emissions are corrected for ethanol content and fuel volatility.

The exhaust emissions of non-road vehicles and equipment are not sensitive to the various changes in fuel properties (except for volatility) like their on-road vehicle counterparts, mainly because many of them do not yet include advanced fuel controls and 3-way catalysts. Consequently, the gasoline fuel options, with one exception, do not affect significantly affect the emissions of off-road gasoline engines. The one exception is ethanol market share. Ethanol increases permeation emissions from off-road gasoline sources, including portable containers (this is discussed in the section below). It also reduces exhaust HC and CO, and increases NOx. For off-road sources, the impacts of the various fuel changes on exhaust emissions are estimated with the NONROAD model.

4.1.5 Permeation Effects

The permeation effects of ethanol in this report utilize the methods developed in the study by AIR for the American Petroleum Institute (API). [11] 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 Southeast Michigan.

Permeation increases in g/day due to ethanol for various sources are shown in Table 4. These emission increases are for a 65-105F test procedure, and are corrected to lower values for at lower ambient temperatures and diurnal cycles typical of Michigan. These values were developed on tests that used E6, instead of E10. It is possible that this could understate the ethanol permeation impact. Further testing of E10 is planned by the Coordinating Research Council.

Table 4. Permeation VOC Increases for Various Sources due to Ethanol		
Source	Model Year Group	VOC Permeation Increase (g/day)
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

One difference between the API study and this study is ethanol market percentages. In the API study, all of the areas were RFG areas, and therefore the required oxygen market share is 100%. In this study, the baseline ethanol market share is 25%, and we examine scenarios with ethanol market share the same as the baseline, and other market fractions such as 0% and 100%. As it turns out, 0% and 100% are straightforward to examine, because at 0% there is no ethanol increase, and at 100% increase the method can be taken directly from the API study. However, the 25% market share for the baseline and some other scenarios deserves discussion. If the market share is 25%, the key question is what fraction of the in-use fleet has some level of ethanol that causes an increase in permeation? We think it is greater than 25% due to the fact that many vehicle owners are not ”brand-loyal”, and buy gasoline wherever it is least expensive and convenient. However, for this study, we will make the assumption that with a 25% market share, only 25% of the fleet has a level of ethanol in gas tank to cause increased permeation. This is a conservative assumption.

Clearly, more ethanol data are needed to sort out the NOx effects of ethanol on future technology vehicles, and these data are being gathered by the Coordinating Research Council (CRC) at this time.

4.1.6 Development of Fuel Characteristics

The previous section indicates that key fuel parameters are needed to evaluate the emission changes of the various control options. These fuel parameters are needed for both the baseline case and all the control options being considered.

As noted in an earlier section, oxygen content is an input to both the Complex and Predictive Model. As a consequence, fuel parameter information must be developed for both non-ethanol and ethanol fuels separately. The results can then be weighted together by the estimated ethanol market fractions, depending on which control scenario is being evaluated.

4.1.6.1 Baseline gasoline composition

AIR evaluated the Alliance of Automobile Manufacturers gasoline survey data for 2001 and 2002 to determine the baseline gasoline characteristics in SE Michigan. [16] In the Alliance surveys, samples are collected and analyzed for regular ,intermediate, and premium grade gasoline. Sample sizes of the three grades of fuel for 2001 and 2002 are shown in Table 5. The fuels with ethanol are separated from those without. Samples with MTBE (there were a few) were ignored.

Table 5. Fuel Survey Sample Size for Detroit

Ethanol	Year	Season	Regular	Intermediate	Premium	Total
No	2001	Summer	8	1	5	14
		Winter	8	1	5	14
	2002	Summer	7	1	4	12
		Winter	8	1	3	12
Yes	2001	Summer	2	1	1	4
		Winter	3	1	1	5
	2002	Summer	2	1	1	4
		Winter	1	1	1	3
All	All	All	39	8	21	68

Source: Alliance of Automobile Manufacturers North American Fuel Survey, 2001-2002.

The sample sizes indicate 57% of the samples are regular, 12% are intermediate, and the remaining 31% are premium grade. This is a higher weighting of premium and intermediate than sales by grade indicate. Information from a previous study by AIR for SEMCOG indicate that sales of regular grade are about 87%, intermediate is about 4%, and premium is 9%. [17] As a result, fuel properties in the Alliance sample are estimated by grade and re-weighted according to these percentages.

Grade-weighted gasoline properties for 2001 and 2002 combined for summer are shown in Table 6. Results are again separated by oxygen content.

Table 6. Baseline Fuel Properties in Detroit Area

Season	Oxy?	Ethanol (vol %)	RVP (psi)	E200 (%)	E300 (%)	Arom. (Vol %)	Olefins (Vol %)	Benzene (vol %)	Sulfur (wt %)
Summer	Yes	9.4	8.7	50.7	81.8	28.5	7.2	1.2	0.0233
	No	0.0	7.6	44.5	79.6	32.9	8.6	1.5	0.0487
Winter	Yes	9.7	15.0	60.0	83.0	22.1	8.9	0.8	0.0286
	No	0.0	14.4	52.1	81.1	26.7	11.5	1.25	0.0456

Source: Alliance of Automobile Manufacturers North American Fuel Survey, 2001-2002.

The ethanol fuel samples have higher volatility (8.7 as opposed to 7.6) due to the volatility waiver for oxygenated gasoline, and also higher E200 levels, and lower aromatics, olefins, benzene, and sulfur. Ethanol concentrations are just under 10% by volume. The market share of ethanol can also be estimated with the information in Table 5. The percent of regular gasoline with ethanol is 21%, and for premium it is 46% (summer and winter combined). The grade volume-weighted average is 25.1%.

The properties in Table 6 are the baseline fuel properties assumed in this study for calendar year 2002. Between 2002 and 2007, sulfur levels are reduced from the baseline levels to 30 ppm. So, for 2007, 2010, 2015 and 2020, the baseline fuel properties are identical to those in Table 5, with the exception that starting in 2007, the fuel sulfur level is assumed to be 30 ppm (0.0030 wt %).

We have shown the winter fuel properties in Table 6 for reference purposes. This study will not quantitatively examine changes in wintertime emissions, but we will provide qualitative comments on the direction of various gasoline controls on winter CO and PM2.5 emissions.

One of the questions of interest for the baseline fuel is how does the baseline gasoline once low sulfur is fully phased-in (i.e., 2006) compare to Clean Air Act Baseline gasoline, which is used by EPA to estimate the RFG performance requirements? To determine this, the above fuel parameters for summer for both the ethanol and non-ethanol gasoline were input into the Complex Model and compared to Clean Air Act baseline gasoline. The results are shown in Table 7, and compared to the RFG performance requirements (which are also relative to CAA baseline gasoline).

Table 7. Comparison of SEMCOG 2006 Gasoline (positive values are reductions)

Pollutant	2006 SEMCOG Baseline compared to CAA Baseline			Phase 2 RFG Performance Requirement compared to CAA Baseline
	Ethanol	Non-ethanol	Wtd. Avg.	
VOC	7%	16.4%	14.0%	27.4%
NOx	12%	11.4%	11.6%	6.8%
Toxics	21%	11.3%	14.0%	21.5%

The results show that in 2006, the weighted average of ethanol and non-ethanol gasolines in the SE Michigan area will be about 14% cleaner for VOC, 12% cleaner for NOx, and 14% cleaner for toxics than Clean Air Act Baseline gasoline. Thus, the table indicates that there are additional emission reductions available from RFG for VOC and toxics, but perhaps not NOx. However, the results above, since they are based on the EPA Complex model, do not reflect any increase in NOx due to ethanol, nor do they include permeation effects due to ethanol. These factors are considered later in this study.

4.1.6.2 California RFG

This section develops the fuel properties for California RFG, both with and without ethanol. AIR obtained volume-weighted average fuel properties for California Phase 3 RFG from the oil industry stakeholders. [18] These are shown in Table 8.

Table 8. Fuel Properties of California RFG (with Ethanol) in 2004	
Parameter	Value
Volatility (RVP, psi)	6.87
E200 (%)	45.5
E300 (%)	87.9
Aromatics (vol %)	23.0
Olefins (vol %)	4.0
Sulfur (wt %)	0.0011 (11 ppm)
Benzene (vol %)	0.6
Ethanol (vol %)	6.0

For California RFG the properties in Table 8 are used, except for the benzene level. The benzene level is assumed to stay the same as the baseline, which is 1.2% in the summer, and 0.8% in the winter. For the California RFG without ethanol, Alliance survey data were examined in San Francisco for 2001 and 2002 that included four samples (one regular and one premium) that did not have ethanol. The average results of those samples are shown in Table 9.

Table 9. Fuel Properties of California RFG without Ethanol	
Parameter	Value
Volatility (RVP, psi)	7.2
E200 (%)	47.0
E300 (%)	88.4
Aromatics (vol %)	22.7
Olefins (vol %)	5.5
Sulfur (wt %)	0.00083 (8.3 ppm)
Benzene (vol %)	0.5

The values in Table 8 are used to estimate the benefits of Ca RFG without ethanol, except that the benzene level is assumed to be the same as the baseline.

4.1.6.3 Federal RFG

This section develops the fuel parameters for Federal RFG, with and without ethanol. The purpose in predicting fuel properties under these various gasoline scenarios is so that the percent reductions can be computed for the properties with both the Complex and Predictive models.

For RFG, the percent reductions are stipulated by the RFG regulations – VOC must be reduced by 27.4%, NOx must be reduced by 6.8%, and toxics must be reduced by 21.5% from Clean Air Act baseline gasoline, using the Complex model. In section 4.1.6.1, we saw that the ethanol containing SEMCOG gasoline was 14% lower for VOC, 12% for NOx, and 14% for toxics than for Clean Air Act Baseline gasoline. Thus, there are additional VOC and toxics reduction from RFG, but there is a question concerning additional NOx reductions. After Tier II sulfur controls, it appears that NOx overperforms its RFG requirement, so that once Tier II sulfur controls go into place, refiners may be able to back off on NOx controls, if this is possible without negatively impacting VOC and toxics.

To test this condition, one needs to input a likely RFG formula that meets the VOC and NOx performance criteria, and then adjust other properties that affect only NOx until the minimum 6.8% reduction is met. We tried a few of these. For example, when we incorporated Tier II sulfur of 30 ppm, added 3.4 wt% ethanol, volatility of 6.7 psi RVP, with E200 at 50, E300 at 81, aromatics at 28% olefins at 7.2% and benzene at 1.2%, we found that the VOC and toxics performance requirements were met (27.5% reduction for VOC, 23.2% for toxics), but the NOx reduction was 12.6%. We then tried to adjust other fuel parameters one-by-one until the NOx was reduced, hopefully without adversely affecting the VOC and toxics performance. The results were that the NOx reductions could not be reduced below about 12% without adversely affecting the other components. Thus, once VOC and toxics are optimized for Federal RFG, we do not think the NOx overperformance can be reduced significantly.

As a result of the above exercise, we think that RFG reductions for the Detroit area - post Tier II sulfur controls - will likely be close to 27.5% for VOC, 21.5% for toxics, and about 12% for NOx, as compared to Clean Air Act baseline gasoline, using the Complex model. The reductions relative to both ethanol and non-ethanol containing SEMCOG baseline gasolines for 2006+ are shown in Table 10.

Table 10. Federal RFG (with ethanol) Reductions vs SEMCOG Baseline

Pollutant	Reductions vs CAA Baseline			RFG vs SEMCOG Baseline Gasoline	
	Baseline with ethanol	Baseline without ethanol	RFG Requirement	With ethanol	Without ethanol
VOC	7%	16.4%	27.4%	22%	13.0%
NOx	12%	11.4%	6.8%	0%	0.0%
Toxics	21%	11.3%	21.5%	0%	11.5%

The results in Table 10 show that RFG may be about 22% lower for VOC than SEMCOG baseline gasoline without ethanol, and about 13% lower for VOC than baseline gasoline with ethanol. For toxics, RFG may be about 12% lower than SEMCOG baseline without ethanol.

While the above analysis estimates the approximate reductions based on the Complex model, this analysis still must develop fuel properties to use in the Complex and Predictive Models. One option is to use the properties developed above that appear to meet the minimum requirements (except for NOx). Another option is to evaluate properties in a nearby RFG area such as Chicago from the Alliance surveys. These results are shown for 2001 and 2002 for Chicago in Table 11.

Table 11. Fuel Properties in Chicago									
Season	Year	EtOH Concen.	RVP (psi)	E200 (%)	E300 (%)	Arom. (Vol %)	Olefins (Vol %)	Benzene (vol %)	Sulfur (wt %)
Summer	2001	10.0	6.75	45.6	84.4	22.76	4.60	0.99	0.0118
	2002	10.0	6.80	44.9	84.2	20.30	5.20	0.74	0.0144
	Avg	10.0	6.78	45.3	84.3	21.53	4.90	0.87	0.0131
Winter	2001	10.0	14.30	60.8	85.1	17.66	8.87	0.95	0.0302
	2002	10.0	14.38	60.3	84.9	17.05	5.06	0.89	0.0295
	avg	10.0	14.34	60.5	85.0	17.36	6.96	0.92	0.0298

Source: Alliance of Automobile Manufacturers North American Fuel Survey, 2001-2002.

In 2006, the sulfur levels in the Chicago area will drop to about 30 ppm. When the average 2001-2002 summer properties for Chicago, along with 30 ppm for sulfur, are input into the Complex model, VOC is reduced by 28%, NOx by 14.8%, and toxics by 30%. These reductions are greater than the RFG performance requirements (27.4% for VOC, 6.8% for NOx, and 21.5% for toxics).

While the Chicago properties post sulfur control appear to overperform the RFG requirements, this analysis will use the Chicago 2001-2002 average properties shown in Table 12 for estimating the benefits of RFG in Detroit. It should be recognized that refiners will have an incentive to modify the fuel properties to reduce the extent of overperformance, although as we have seen earlier, the overperformance for NOx cannot be eliminated. Thus, the emission benefits for RFG as estimated here may be a little greater than what actually occurs. However, it is not possible for us to guess at this time how refiners will reduce the overperformrance.

For RFG without ethanol, we ran the Complex model, and changed the RVP, E200 and E300 slightly to meet the 27.4% VOC performance specification. Aromatics and olefins were increased slightly. Benzene and sulfur were assumed to be the same as the Chicago RFG with ethanol.

Table 12. Fuel Properties Assumed for Federal RFG in Detroit – Summer								
Ethanol	EtOH Concen. (vol %)	RVP (psi)	E200 (%)	E300 (%)	Arom. (Vol %)	Olefins (Vol %)	Benzene (Vol %)	Sulfur (wt %)
Yes	10.0	6.8	45	84	22	4.9	0.87	0.0030
No	0.0	6.7	46	85	24	5.5	0.87	0.0030

4.1.6.4 Lower Sulfur

The lower sulfur option in this study assumes a sulfur average of 10 ppm. This analysis will assume that all other properties are the same as the baseline, and only sulfur is reduced to 10 ppm. The fuel properties for this option for 2006 and later are shown in Table 13.

Table 13. Low Sulfur Fuel Properties for Detroit Area									
Season	Oxy?	Ethanol (vol %)	RVP (psi)	E200 (%)	E300 (%)	Arom. (Vol %)	Olefins (Vol %)	Benzene (vol %)	Sulfur (wt %)
Summer	Yes	9.4	8.7	50.7	81.8	28.5	7.2	1.2	0.0010
	No	0.0	7.6	44.5	79.6	32.9	8.6	1.5	0.0010
Winter	Yes	9.7	15.0	60.0	83.0	22.1	8.9	0.8	0.0010
	No	0.0	14.4	52.1	81.1	26.7	11.5	1.25	0.0010

4.1.6.5 Lower Volatility in Summer, with Ethanol Waiver

This study evaluates lowering the volatility of the baseline gasoline to 7.0 psi RVP in the summer. It is likely that the fuel properties for this option can be determined by merely lowering the volatility below 7 psi. For example, with a 7.8 psi limit, the current volatility of gasoline without ethanol is 7.6 psi, or 0.2 psi below the limit of 7.8 psi. Therefore, the volatility of the gasoline without ethanol would be expected to be 6.8 psi, and that with ethanol would be expected to be 7.8 psi.

One concern with lowering RVP significantly is that it can lead to higher T10 and T50 levels, and can increase exhaust HC emissions if T10 and T50 rise too much. The industries use an index called the driveability index (DI) to determine acceptable limits on the distillation properties of gasoline. The DI equation is shown below:

$$DI = 1.5 * T10 + 3.0 * T50 + T90 \text{ [19]}$$

Gasoline with high DIs can cause driveability problems. Different vehicles respond differently, but in recognition that distillation properties affect both driveability and emissions, the ASTM has adopted a maximum DI of 1250 for U.S. fuels. The Alliance of Automobile Manufacturers World Fuel Charter recommends a lower maximum DI of 1180. In addition, the Alliance recommends the use of an extra term if ethanol is being used.

When fuel volatility is lowered, this causes a rise in T10 and, to a lesser extent, T50. This in turn raises the DI of the fuel. To examine this issue further, we examined the DI's of Detroit fuels at 7.8 psi, versus two other locations that currently have 7.0 psi fuel – Atlanta and Kansas City. Atlanta implemented 7 psi in 1999, Kansas City in 2001. Results are shown in Table 14. The comparison in Table 13 is only for non-oxygenated fuels.

Table 14. Comparison of Driveability Indices			
City	Volatility Limit (psi)	T50	DI
Atlanta	7.0	223	1213
Kansas City	7.0	222	1217
Detroit	7.8	219	1196

Source: Alliance of Automobile Manufacturers North American Fuel Survey, 2001-2002.

Table 14 shows that both Atlanta and Kansas City, which have 7 psi fuel, have slightly higher average DIs than Detroit. However, both are significantly below the 1250 limit. The T50 values are about 3-4º F higher than Detroit. Based on this comparison, if Detroit lowers the volatility of the fuel to 7.0, it appears that the T50 level could increase by about 3º F. Therefore, we will examine two cases – one in which the T50 level does not change, and one in which the T50 value increases by 3º F.

4.1.6.6 Ethanol Market Share

Two cases are examined – 0% ethanol, and 100% E10 market share. For the 0% ethanol cases, the properties assumed are the same as the non-ethanol baseline for 2006+. For the 100% E10 market share cases, the properties are the same as the ethanol baseline case for 2006+.

4.1.6.7 Summary of 2006+ Properties

The gasoline properties for each of the alternatives are summarized in Table 14. Note there is considerable uncertainty in projecting future fuel properties in Southeast Michigan for the various cases studied. So, actual future fuel properties could differ markedly from those projected in Table 15.

Table 15. Gasoline Properties Assumed for the 2006 and Beyond, Summer

Scenario	ETOH	ETOH Mkt %	ETOH Concen. Vol%	RVP psi	E200 %	E300 %	Arom. Vol %	Olef. Vol %	Ben Vol %	Sulfur Wt %
Baseline	Yes	25	9.4	8.7	50.7	81.8	28.5	7.2	1.2	0.0030
	No	75	0.0	7.6	44.5	79.6	32.9	8.6	1.5	0.0030
Ca RFG	Yes	100	6.0	6.9	45.5	87.9	23.0	4.0	1.2	0.0011
Ca RFG, w/o E6	No	0	0.0	7.2	47.0	88.4	22.7	5.5	1.2	0.0008
RFG	Yes	100	10.0	6.8	45.0	84.0	22.0	4.9	0.87	0.0030
RFG w/o E10	No	0	0.0	6.7	46.0	85.0	24.0	5.5	0.87	0.0030
Low Sulfur	Yes	25	9.4	8.7	50.7	81.8	28.5	7.2	1.2	0.0010
	No	75	0.0	7.6	44.5	79.6	32.9	8.6	1.5	0.0010
7 RVP	Yes	25	9.4	7.8	50.7	81.8	28.5	7.2	1.2	0.0030
	No	75	0.0	6.8	44.5	79.6	32.9	8.6	1.5	0.0030
7 RVP, 3 ºF higher T50 (lower E200)	Yes	25	9.4	7.8	49.4	81.8	28.5	7.2	1.2	0.0030
	No	75	0.0	6.8	43.1	79.6	32.9	8.6	1.5	0.0030
No E10	No	0	0.0	7.6	44.5	79.6	32.9	8.6	1.5	0.0030
100% E10	Yes	100	9.4	8.7	50.7	81.8	28.5	7.2	1.2	0.0030

The NONROAD model does not have the same inputs for ethanol market fraction and concentration as MOBILE6, nor does it estimate the effects of commingling. The model allows only the input of RVP and oxygen weight percent. To estimate emissions for the baseline case that assume 25% of fuel contains ethanol, and 75% does not, weighted average RVP and ethanol concentrations must be estimated. The RVP and ethanol weight percent values used in NONROAD for the different fuel cases are shown in Table 16. For the baseline case, these were estimated from the data in Table 15. The low sulfur case is not shown because it is not estimated to have an effect on VOC, CO, and NOx emissions in NONROAD.

Table 16. RVP Levels and Oxygen Weight Percents Used in NONROAD

Case	RVP	Oxygen Vol % (wt%)
Baseline	7.87	2.4 (0.8)
Ca RFG	6.9	6.0 (2.0)
Ca RFG w/o E6	7.2	0.0 (0.0)
RFG	6.8	10.0 (3.4)
RFG w/o E6	6.7	0.0 (0.0)
Low RVP	7.05	2.4 (0.8)
No E10	7.6	0.0 (0.0)
100% E10	8.7	10.0 (3.4)

4.2 Diesel Programs

The impacts of four types of potential diesel programs were examined for the SEMCOG region. The four programs are as follows.

- Diesel Cetane Programs
- California Diesel Programs
- Biodiesel Programs
- Diesel Retrofit Programs

The first three are strictly fuel programs in which specific properties of diesel marketed in the region would be required to meet regulatory standards. The fourth program, diesel retrofits, examines the impacts of implementing exhaust after-treatment devices on in-use vehicles already operating on the road. Diesel retrofits could be a stand-alone program or could be used in combination with one of the three diesel fuel programs.

Section 4.2 provides an overview of these four diesel programs including an overview of each, modeling assumptions including key estimates of fuel parameters and outlines the inventory modeling methodology. This section is broken down into the following topics.

- <u>Description of Diesel Programs</u> (Section 4.2.1) presents an overview of the diesel programs modeled for this project.

- <u>Program Implementation Assumptions</u> (Section 4.2.2) summarizes the program implementation assumptions such as start-up date and fleet coverage used in the inventory analyses.

- <u>Overview of Modeling Methods, Tools and Data</u> (Section 4.2.3) describes the overall modeling tools, methods and data common to all the programs evaluated.

- Program Specific Modeling Methods (Section 4.2.4) describes the specific methods for each of the four diesel programs.

4.2.1 Description of Diesel Programs

The following describes an overview of each of the four diesel programs studied. Preceding these discussions is an overview of the baseline diesel specifications.

4.2.1.1 Baseline Diesel

Michigan's motor fuel regulations do not include a standard for diesel fuel content. Regulations on the distribution and sale of diesel are included in the Department of Agriculture Weights and Measures Act. As such, specific diesel content requirements are those established by the federal government. Impacting this analysis are recently enacted requirements for ultra-low sulfur diesel (maximum sulfur content of 15 ppm), which is required in on-road applications in 2006 and in off-road applications in 2010. Because of differing sulfur requirements, two separate diesels are marketed in Michigan, on-road diesel and off-road diesel.

4.2.1.2 Diesel Cetane Programs

Cetane is a measure of diesel fuel ignition quality. It is a scale of autoignitability for which a higher value signifies improved autocombustion and has shown to improve (i.e., reduce) engine out emissions in 2002 and older vehicles only. The primary test method is ASTM D613, which calculates the "cetane number" of the tested diesel.

Currently there are no programs in place in the U.S. that specify diesel Cetane levels;[2] however, according to the EPA there is enough interest in possible programs that the Agency has released guidelines for estimating emission inventory credits for cetane programs as part of the State Implementation Plan (SIP) development efforts currently underway.

Cetane can be improved through additives, of which the most common additives are 2-ethylhexyl nitrate and ditertiary butyl peroxide. Because of the use of additives, the "natural" cetane number is defined to refer to the cetane measured for the fuel without any additives present and a total cetane number would then be the cetane of the fuel including additives, if present.

The impacts of two diesel cetane programs were evaluated in this study: a program that covers on-road diesel and a second that covers both on- and off-road diesel. For each, the cetane program is assumed to result in an average cetane number of 50, where the increase in cetane number (over that observed in current Michigan diesel) would be achieved through cetane additives. For example, if the baseline on-highway diesel has a cetane level of 42, then a program requiring a 50 cetane level would involve

[2] Cetane is one of the diesel properties included in the California diesel regulations.

changes to the natural cetane number, cetane additives, or some combination of both such that the final diesel had a cetane of 50. For the second program that would also cover off-highway diesel, similar modifications would have to be made. The validity of assuming that diesel fuels supplied to Michigan can achieve an average cetane number of 50 with cetane additives has not been confirmed.

4.2.1.3 California Diesel Programs

California has enacted diesel regulations governing sulfur and aromatics content. In addition, compliance with the regulation can be met through demonstrating emissions equivalence to a reference fuel, which encompasses multiple specifications (including cetane described above). Most diesel marketers rely on the equivalency demonstration to meet the California requirements. In April 2000, Texas adopted its Low Emission Diesel (LED) regulation, which was modeled after the California program.

The impacts of two California diesel programs were evaluated as part of this study: a program that covers on-road diesel and a second that covers both on- and off-road diesel.

4.2.1.4 Biodiesel Programs

Biodiesel refers to a fuel where diesel has been combined with oils from a renewable source (either plant-based or animal-based fats). Several demonstration programs have been completed, and in general biodiesel has been shown to reduce PM, VOC, and CO emissions while increasing NOx emissions. In July of this year, EPA issued grants to five states to run Clean School Bus Programs operating on biodiesel.

In this study, two biodiesel programs were examined: one with a 5 percent renewable content (B5) and one with a 20 percent renewable content (B20). However, there is no approved specification for B20, and currently, the engine manufacturers do not recommend the use of B20 in their vehicles.

4.2.1.5 Diesel Retrofit Programs

EPA has developed the Voluntary Diesel Retrofit Program to provide guidance on reducing emissions from vehicles and equipment already in-use. Retrofits refer to a wide range of emission control technologies that can be applied to vehicles to help reduce in-use emissions which have a varying degree of effectiveness. California also has its own retrofit programs and requirements. Recently EPA and CARB signed a Memorandum of Understanding (MOU) permitting cross-agency use of certification and verification results designed to increase the number of retrofit options available to state and local planning agencies.

Three levels of diesel retrofit programs were examined in this study, which are defined by the emissions control achieved by the retrofit devices. These levels were defined by the natural groupings of similar technologies found in the EPA and CARB certification data.

4.2.2 Program Implementation Assumptions

For this study, it was assumed that each of these diesel programs would be in place on or before 2007 (assumed implementation is 2006).

Each program was assumed to achieve 100 percent implementation or coverage over the 7-county SEMCOG region in all analyses reported in this document. As such, all applicable diesel engines would operate under the specifics of each program.[3]

For the three fuel programs (cetane programs, California diesel and biodiesel), 100 percent coverage is not unreasonable for non-road engines, but is unlikely for heavy-duty vehicles that can fuel outside the program domain but operate within the SEMCOG region. The occurrence of this would depend on the size of the region subject to the proposed regulation. According to EPA guidance, if the fuel is only required in the 7-county area, then an appropriate level of coverage would be 80 percent, which accounts for the proportion of diesel activity relying on fuels obtained outside the regulatory domain.[4] [20] If the fuel regulation covers the whole state, then 100 percent implementation is reasonable. Note that program benefits are a linear function of percent implementation, so results can be scaled to any implementation assumption that is found to be appropriate. Regardless of the region covered by the regulation, it would be expected that the off-road sector in the SEMCOG area would be fueled by diesel that meets local fuel requirements (i.e., 100 percent coverage).

In the case of diesel retrofits, achieving 100 percent implementation of all vehicles operating in the region is not realistic. In Michigan about 36 percent of truck activity is from centrally-fueled, local fleets according to the Vehicle Inventory and Use Survey. [21] These are the types of vehicles that are suitable candidates for retrofit programs, since the vehicle activity is falling largely within the local area of the central fueling location. Based on this information, a 40 percent implementation rate might be a good target of what is possible to achieve with diesel retrofits. Again, scaling these results to a target implementation rate can be easily completed as the benefits are a linear function of the implementation rate. However, future retrofit programs of evaluation may target a specific fleet of known vehicles with known operating characteristics. To facilitate analyses at this scale, this study also provides estimates for retrofit benefits on a per-vehicle basis.

4.2.3 Overview of Modeling Methods, Tools and Data

The following describes the overall modeling tools, methods and data common to all the programs evaluated.

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[3] In certain instances, benefits are only realized by specific model year groups of the fleet.
[4] This is based on the total area, in square miles, of the 7-county area.

On- and off-road diesel emission inventories were evaluated for the 7-county SEMCOG modeling domain. Scenarios examined include the Baseline (current diesel program), cetane programs, California diesel programs, biodiesel programs and diesel retrofit programs. Calendar years of evaluation include 2002 (Baseline only), 2007, 2010, 2015 and 2020. Pollutants examined include HC, CO, NOx, PM and HC-based toxics compounds (1,3-butadiene, benzene, acrolein, acetaldehyde and formaldehyde).

On-road emission inventories were evaluating using EPA's MOBILE6.2 emission factor model. [22] MOBILE6.2 produces emission factors in grams per mile (g/mi) which are combined with SEMCOG's travel demand model output (vehicle miles traveled and vehicle speeds) to estimate on-road inventories. This inventory method follows the procedures developed by SEMCOG for their SIP modeling efforts.

The latest EPA off-road model, Draft NONROAD2004, was used to estimate diesel off-road inventories for the 7-county area. [23] Diesel inventories include the wide range of off-road equipment and vehicles. The off-road inventories do not include emissions from trains, commercial marine vessels or aircraft.

On-road diesel properties were developed from fuel survey data obtained from the Alliance of Automobile Manufacturers. Survey data are collected from the Wayne County area and are reflective of fuels sold in the modeling domain. [24]

Spillover accounts for the proportion of off-road applications using on-road diesel. The spillover rate assumed in this study is that estimated by EPA for PADD II (this region includes the State of Michigan) in the recent 2004 rulemaking for off-road diesel engines. This rate was estimated at 26.9 percent. [25]

4.2.4 Program Specific Modeling Methods

The following describes the specific modeling methods for the Baseline and each of the four diesel programs.

4.2.4.1 Baseline Diesel Fuel Characteristics

The Baseline diesel fuel characteristics for this study are summarized in Table 17. The 2002 on-road data represent the 2001-2002 average of diesel properties estimated from Alliance fuel survey data. Off-road specific diesel represents diesel fuel marketed for off-road applications. Very little off-road fuel survey data exist nationally and in this case, the off-road diesel properties were assumed to be the same as on-road except for sulfur and cetane, which were determined in consultation with EPA. [26] Off-road average properties include the effects of spillover.

Table 17. Baseline Diesel Properties in SEMCOG Area										
Diesel Fuel	Calendar Year	Diesel Parameter								
		Sulfur, ppm	Cetane Number	Additized Cetane Increase	Natural Cetane Number	Aromatics, vol%	Specific Gravity	T10, °F	T50, °F	T90, °F
On-road	2002	365	42	1	41	39.3	0.858	423	499	593
	2006-09	11	43	1	42	39.3	0.858	423	499	593
	2010+	11	43	1	42	39.3	0.858	423	499	593
Off-road Specific	2002	3330	40	1	39	39.3	0.858	423	499	593
	2006-09	350	42	1	41	39.3	0.858	423	499	593
	2010+	11	43	1	42	39.3	0.858	423	499	593
Off-road Average	2002	2510	41	1	40	39.3	0.858	423	499	593
	2006-09	259	42	1	41	39.3	0.858	423	499	593
	2010+	11	43	1	42	39.3	0.858	423	499	593

Source: Alliance of Automobile Manufacturers North American Fuel Survey, 2001-2002.

Further comments on the development of these data are as follows.

- The 2006 and later on-road sulfur and cetane number values are based on a review of ultra-low sulfur diesel (ULSD) rulemaking and EPA consultation. The 15 ppm sulfur requirement modeled as 11 ppm; cetane number is expected to increase by 1 due to ULSD.[26] Aromatics and T90 may also change, but we do not know by how much, so they have been held constant.

- The 2002 sulfur levels are the national off-road average used in off-road CI rulemaking. 2005-2009 sulfur levels are those assumed by EPA for 500 ppm sulfur limit. 2010+ off-road ULSD is modeled as done with on-road.

- The off-road cetane number is estimated relative to local on-road values. The 3330 ppm sulfur off-road diesel would have a value about 2 points below the current on-road value (EPA recommendation).[26]

- Baseline inventory estimates are those from MOBILE6.2 without adjustment for fuel properties. The baseline fuel properties were used as the reference point from which the impacts of other fuel programs were determined.

4.2.4.2 Modeling Diesel Cetane Programs and Fuel Characteristics

This study relied on EPA guidance methodologies for estimating the emission impact of cetane on diesel exhaust emissions, however, there are data limitations in EPA's guidance. For example, only one 1997-2001 model year engine was present in EPA's database. The impact on NOx emissions was calculated using EPA guideline equations developed in 2003 and 2004. [26,27] VOC, PM2.5 and CO emissions impacts were derived using equations, provided by the EPA, that were developed in a manner analogous to the NOx reference study. [26] The impacts of two diesel cetane programs were evaluated in this study: a program that covers on-road diesel and a second that covers both on- and off-road diesel.

The fuel parameters that factor into the estimate of cetane program benefits are the natural cetane number and the additized cetane increase. It was assumed that the 50 cetane average under the proposed cetane programs would be met by increasing the quantity of additives. [5] The resulting diesel properties used for modeling the impacts of cetane programs are summarized in Table 18. The emissions impact is estimated as the difference between the diesel properties under the cetane programs as compared to the Baseline diesel (Table 16).

Table 18. Diesel Properties for Cetane Programs.

Cetane Program	Fuel	Years	Natural Cetane Number	Additized Cetane Increase	Total Cetane
On-road Program	On-road Diesel	2007+	42	8	50
	Off-road Average Diesel	2007 only	41	3	44
		2010+	42	3	45
On- and Off-road Program	On-road Diesel	2007+	42	8	50
	Off-road Average Diesel	2007 only	41	9	50
		2010+	42	8	50

The 50 cetane program for on-road vehicles results in a 50 cetane for on-road diesel fuel, and 44-45 cetane for off-road. The increase of about 3 cetane for off-road is the result of spillover of on-road to off-road diesel fuel.

Other comments on the fuel properties and other modeling assumptions are as follows.

- EPA recommends applying on-road cetane impacts for only non-EGR equipped vehicles (2002 and earlier vehicles). This guidance was followed.

- EPA's review of the effect of cetane on light duty diesel emissions concludes that there is no apparent effect on emissions, so no effect was estimated in this study for light duty diesel vehicles or light duty diesel trucks.

- There are no data on light-duty off-road engines (≤50 hp) and no impact is modeled (consistent with EPA recommendations).

[5] Cetane increases on the order of 8 or 9 through the use of additives are significant and may not always be possible for a refiner.

- There are insufficient data on individual toxic species. HC-based toxics are estimated to change in proportion to HC exhaust changes (i.e., the proportion of HC-based toxics found in HC exhaust is held constant).

4.2.4.3 California Diesel Programs and Fuel Characteristics

This study relied on EPA guidance methodologies for estimating the emission impact of California diesel, which were used to estimate the impacts of the Texas Low Emission Diesel program in June 2001. [28] The impacts of two California diesel programs were evaluated as part of this study: a program that covers on-road diesel and a second that covers both on- and off-road diesel.

Based on EPA's method, the average properties observed in California diesel are those by which the benefits of the program are evaluated elsewhere. The average properties for the California programs as applied in this study are summarized in Table 19. Properties for California diesel are taken from the EPA reference. The emission impact is based on the difference between the diesel properties under the California programs as compared to the Baseline diesel (Table 17).

Table 19. Properties for California Diesel Fuel Program

California Program	Fuel (Years)	Diesel Parameter								
		Sulfur, ppm	Cetane Number	Additized Cetane Increase	Natural Cetane Number	Aromatics, vol%	Specific Gravity	T10, °F	T50, °F	T90, °F
On-road	On-road (All)	11	52	4	48	21.9	0.837	418	502	613
	Off-road Average (2007)	259	45	2	43	34.6	0.852	0	422	500
	Off-road Average (2010+)	11	45	2	43	34.6	0.852	0	422	500
On- and Off-road	All (All)	11	52	4	48	21.9	0.837	418	502	613

Table 19 illustrates what one ULSD fuel might look like. It is a lighter fuel than the baseline diesel but interestingly it has a higher T90 (613 vs 593) and has much lower aromatics (21.9 vs 39.9).

Other comments on the fuel properties and other modeling assumptions are as follows.

- EPA recommends applying California diesel impacts for only non-EGR equipped vehicles (2002 and earlier vehicles). This guidance was followed.

- No data or equations are provided by EPA for CO, therefore, CO impacts were not modeled.

- EPA states that studies of light-duty diesel emissions and diesel fuel parameters are inconclusive. EPA recommends no effect to be modeled for light-duty diesel, which is the approach taken.

- The equations employed in this analysis contain no data from light-duty off-road engines (≤50 hp) and therefore no impact was estimated for these.

- There are insufficient data on individual toxic species. HC-based toxics are estimated to change in proportion to HC exhaust changes.

- Due to the equivalency requirement of California diesel, which is the regulatory path most marketers have taken in California, actual fuel sold in Southeast Michigan will likely be different from those in California. There is no way to predict what the specific results of a Michigan regulation would be, so use of the average California fuel properties is the best approximation.

4.2.4.4 Biodiesel Programs

This study relied on current EPA guidance methodologies for estimating the emission impact of biodiesel. [29] There are no fuel properties needed to evaluate the emission effects of biodiesel other than the percent of biodiesel. In this study, there are two fuels quantified, 5% biodiesel and 20% biodiesel. This study looked at only an on-road biodiesel requirement. The emissions test data for off-road engines are inconclusive and preliminary impacts appear to be different from the on-road impacts. At this time, there is insufficient data to determine the impact for off-road diesel applications. Not modeling an off-road impact is consistent with current EPA guidelines.

In the biodiesel analyses completed, this study relied on EPA's data compiled from all types of biodiesel without distinction. Most of the data are from vegetable oils (soybean and rapeseed/canola) with the remainder from animal fats. EPA's reference does include composite analyses (all biodiesel types combined) as well as analyses by individual type of biodiesel. Additional notes on the methodology are as follows.

- EPA recommends applying reductions to both EGR and non-EGR equipped vehicles, which was followed as well.

- The emissions impact of biodiesel use in off-road applications was not modeled. This follows EPA guidelines, which states that off-road impacts are inconclusive (and appear to be different from on-road benefits). A separate analysis carried out by AIR under another project suggests that biodiesel impacts vary by engine size and test cycle which makes extrapolating to off-road applications highly uncertain.

- Little data exists for light-duty on-road diesel vehicles and no impact was modeled, which follows EPA's recommendation.

- Limited test data on individual toxic species suggest that biodiesel emits different proportions of individual toxics than conventional diesel, but these data are highly variable. Formaldehyde and acetaldehyde results have the least amount of variability and results appear to be consistent. In this study, these two species were modeled using equations specific to these compounds. For other key mobile source toxics species (1,3-butadiene, benzene and acrolein), it generally appears that levels decline (at a rate less than the decline in HC emissions) but the data are not conclusive. We modeled no change in emissions from these three compounds under the proposed biodiesel programs.

4.2.4.5 Diesel Retrofit Programs

Three levels of diesel retrofits were modeled based on a minimum PM reduction performance estimated. The three levels are as follows.

Level 1: 20 percent reduction in PM
Level 2: 60 percent reduction in PM
Level 3: 85 percent reduction in PM

These levels were the result of a review of the current certified technologies and appear to be the most natural groupings. Very few technologies have been approved for off-road applications. Therefore, only on-road engines are assumed to be covered by the retrofit program. Note that EPA and CARB recently signed a Memorandum of Understanding (MOU) to accept the other agency's certification and verification results. Information on technologies currently verified by EPA and CARB can be found at the following web pages:

http://www.epa.gov/otaq/retrofit/
http://www.arb.ca.gov/diesel/verdev/verdev.htm

Specific assumptions for each level are as follows.

Retrofit technologies falling under Level 1 are typically diesel oxidation catalysts (DOCs), of which several manufacturers have products. Some technologies verified for model years older than 1991, and some verified only for 1991 through 2002 model years. In this study we assumed that the retrofits would be applied to 1991 to 2002 model year on-road engines only. For Level 1 technologies the percent reductions assumed are shown below. It was assumed that HC-based toxics would change in proportion to HC changes.

- PM, 20%
- HC, 40%
- CO, 40%

- NOx, 0%

Retrofit technologies falling under Level 2 include coupled DOC and particulate filters. Technologies verified for model years 1994 through 2002, which is the assumed target model year group in this study. For Level 2 technologies, the percent reductions assumed are shown below. It was assumed that HC-based toxics would change in proportion to HC changes.

- PM, 60%
- HC, 60%
- CO, 60%
- NOx, 0%

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Retrofit technologies falling under Level 3 include particulate filters with muffler system (which includes a DOC) and coupled DOC and particulate filters. Technologies require ultra-low sulfur diesel (ULSD) fuel to achieve reduction targets (ULSD is required for all on-road diesel by 2006). Technologies are verified for model years 1994 through 2002, which is the assumed target model year group in this study. For Level 3 technologies, the percent reductions assumed are shown below. It was assumed that HC-based toxics would change in proportion to HC changes.

- PM, 85%
- HC, 75%
- CO, 75%
- NOx, 0%

5.0 Results

5.1 Gasoline Options

This section presents the results of the gasoline options. The baseline inventories, without the gasoline cases as examined in this report, are presented first. This is followed by a discussion of the on-road exhaust results, the on-road evaporative results, and the off-road results. Next, the permeation results are presented. Finally, all of the gasoline results are summarized.

There are numerous complexities associated with evaluating the wide spectrum of fuels targeted for analysis in this study. Subtle but important information would be lost by proceeding directly to “bottom-line” changes in the inventory. Therefore, information is presented in incremental fashion so that important subtleties could be identified and appropriately considered in the policy making phase when choices about what programs to implement will be determined Therefore, readers are cautioned not to reach conclusions before all the incrementally developed information is aggregated so that cumulative impacts can be fairly assessed.

5.2 Baseline Inventories

Baseline summer inventories for on-road and off-road sources in the Southeast Michigan area for 2002-2020 are shown in Table 20. The baseline inventories provide context for evaluating the benefits of the various fuel scenarios previously described. These inventories were developed using the baseline fuel properties for sulfur, ethanol, ethanol market share, and fuel volatility as needed for the MOBILE6.2 model. The modeling also accounts for growth in vehicle miles traveled supplied by SEMCOG. For consistency, growth in travel was estimated using the same procedures as in developing the federally required regional Transportation Plan.

Table 20. Baseline On-Road and Off-Road Inventories for Southeast Michigan (Gasoline and Diesel – Tons per Summer Day)

	On-Road				Off-Road			
Year	VOC[1]	NOx	PM2.5[2]	CO	VOC[1]	NOx	PM2.5[2]	CO
2002	177	463	7.1	2412	65	65	6.1	1034
2007	106	279	4.2	1257	48	59	5.2	1119
2010	86	211	3.1	1094	39	48	5.0	1145
2015	62	114	2.0	906	34	35	4.1	1196
2020	54	71	1.6	848	34	27	3.3	1282

[1]Includes both exhaust and evaporative emissions but does not include any increase in permeation VOC emissions due to current ethanol market fraction of 25%.
[2]Exhaust emissions only.

The inventory shows that, even without any additional fuel controls, large reductions in VOC, NOx, and PM2.5 are expected to occur. For example, on-road VOC drops by 71 tpd (40%) from 2002 to 2007, and on-road NOx drops by 184 tpd (40%)

over the same period. These reductions are the result of the phasing in of existing new federal regulations, most notably more stringent vehicle emission (Tier II) standards and reduced sulfur in gasoline and diesel fuel.

These are very significant reductions which, as will be shown are several times greater than can be accomplished with any fuel modification. There are also substantial reductions in VOC, NOx, and PM for off-road sources. In addition to the VOC and NOx reductions, CO from on-road vehicles declines from 2412 tpd in 2002 to 848 tpd in 2020. Off-road CO increases somewhat over the same period.

5.3 On-road Exhaust Results

5.3.1 Complex Model Results

The percent change in each of the gasoline cases versus the CAA Baseline fuel, using the Complex model, is shown in Table 21. The negative values indicate a benefit in the table. The percent benefits of each of the gasoline proposals relative to the SEMCOG baseline gasoline are shown in Table 22, and shown graphically in Figure 1. Positive results in Table 22 and Figure 1 indicate a benefit versus SEMCOG baseline gasoline. These are estimated from the percent emission changes in Table 21 and the method outlined in Attachment A. VOC and NOx are exhaust only, but toxics changes are shown as both exhaust and evaporative toxic differences.[6]

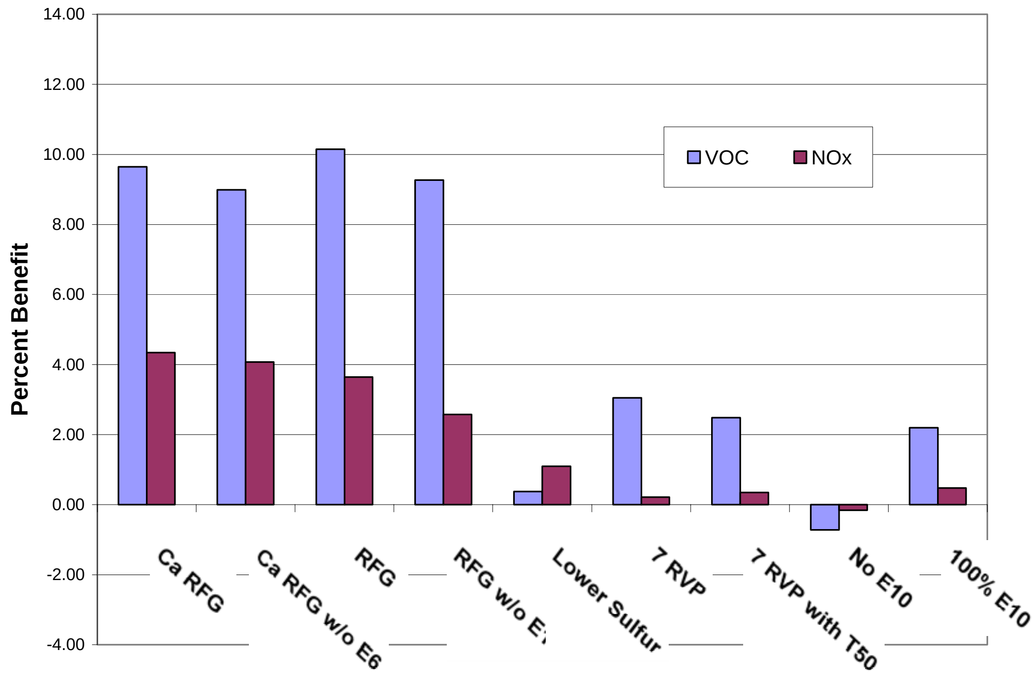
[6] Evaporative VOC emissions are estimated with the MOBILE6.2 model, but for toxics, we will use the COMPLEX Model's evaluation of both exhaust and evaporative emissions.

Table 21. Percent Changes in Exhaust Emissions vs. Clean Air Act Baseline Using Complex Model, Summer 2007			
Case	Exhaust VOC	NOx	Exhaust + Evap Toxics
SEMCOG baseline w/E10	-10.48	-11.99	-20.95
SEMCOG baseline w/o E10	-7.80	-11.43	-11.31
Wtd avg baseline	-8.47	-11.57	-13.72
Ca RFG	-17.3	-15.41	-26.68
Ca RFG w/o E6	-16.70	-15.17	-24.33
RFG	-17.76	-14.79	-29.88
RFG w/o E10	-16.95	-13.85	-27.39
Lower sulfur, w/E10	-10.80	-12.96	-21.40
Lower sulfur, w/o E10	-8.15	-12.40	-11.85
Wtd avg, lower sulfur	-8.81	-12.54	-14.24
7 RVP, w/E10	-13.45	-12.21	-22.20
7 RVP, w/o E10	-10.53	-11.61	-12.19
Wtd avg, 7 RVP	-11.26	-11.76	-14.69
7 RVP, higher T50, w/E10	-13.09	-12.32	-22.03
7 RVP, higher T50, w/o E10	-9.96	-11.73	-11.96
Wtd avg, 7RVP w higher T50	-10.74	-11.88	-14.48
No E10	-7.81	-11.43	-11.31
100% E10	-10.48	-11.99	-20.95

Table 22. Exhaust Benefit of Gasoline Options Relative to SEMCOG Baseline Gasoline Using Complex Model (%)			
Description	Exhaust VOC	NOx	Exhaust + Evap Toxics
Ca RFG	9.65	4.34	15.02
Ca RFG w/o E6	8.99	4.07	12.30
RFG	10.15	3.64	18.73
RFG w/o E10	9.26	2.58	15.84
Lower Sulfur	0.37	1.10	0.60
7 RVP	3.05	0.21	1.13
7 RVP with T50	2.48	0.35	0.88
No E10	0.72	0.16	2.79
100% E10	2.20	0.47	8.38

Note: "Lower sulfur", "7 RVP" and "& RVP w/T50" percent reductions were estimated combining the ETOH and No ETOH cases from Table 19, assuming 25% of the fuel contains ETOH and 75% does not.

Figure 1. Exhaust Emission Percent Benefits Using the COMPLEX Model



Exhaust VOC benefits are the highest for Ca RFG and RFG. The Complex model indicates that the exhaust VOC benefits are less without ethanol than they are with ethanol. Most of the other cases show very small or no VOC benefit. NOx benefits are again highest for Ca RFG and RFG, with slightly less benefit when ethanol is not included. Finally, toxics benefits appear to be greatest for RFG, due to the low benzene assumed for this case. 100% E10 market share also appears to have toxics benefit, due to the fact that the ethanol gasoline in Michigan appears to have lower benzene content (1.2%) than gasoline without ethanol (1.5% - see Table 15).

5.3.2. Predictive Model Results

The percent changes in each of the gasoline cases versus the California Phase 2 gasoline using the Predictive Model are shown in Table 23.[7] The reductions in exhaust emissions of each of the gasoline proposals relative to SEMCOG baseline gasoline are shown in Table 24, and are also shown graphically in Figure 2. These are estimated from the percent changes in Table 23 and the method outlined in Attachment A.

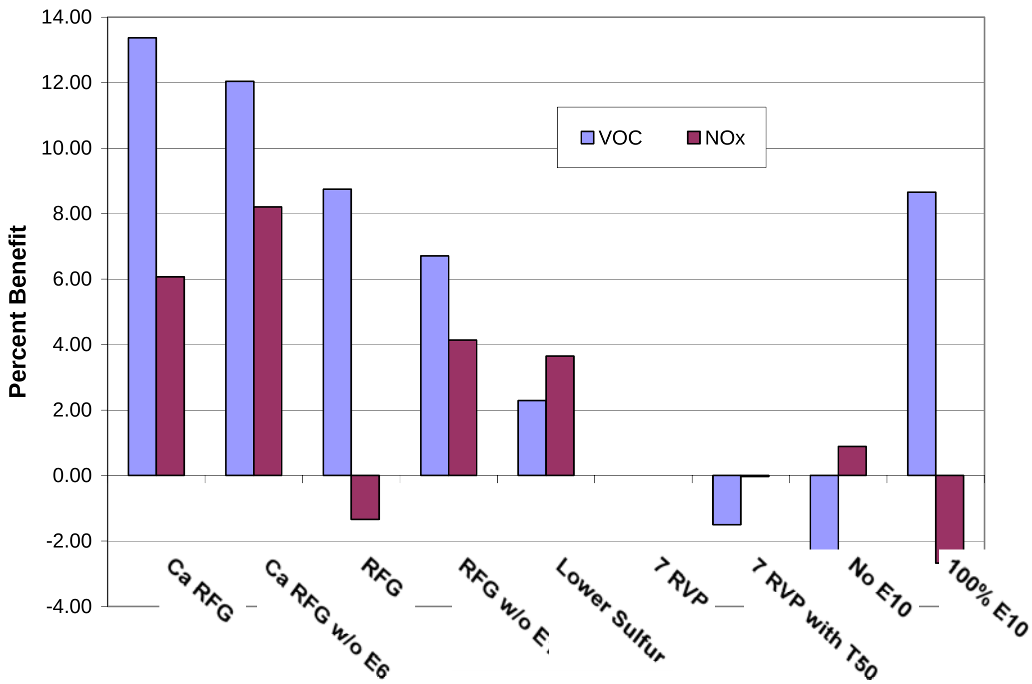
[7] The numbers are not negative as in Table 19, because the various fuels are being compared to California Phase 2 fuel in the Predictive Model, instead of Clean Air Act baseline gasoline.

Table 23. Percent Changes in Exhaust Emissions vs Clean Air Act Baseline Using Predictive Model, Summer			
Case	VOC	NOx	Potency Wtd. Toxics
SEMCOG baseline w E10	6.89	7.67	30.06
SEMCOG baseline w/o E10	16.78	4.29	54.93
Wtd average Baseline	14.31	5.14	48.71
Ca RFG	2.85	-0.62	19.55
Ca RFG w/o E10	3.99	-2.65	20.93
RFG	6.81	6.41	13.35
RFG w/o E10	8.56	1.21	16.21
Low Sulfur, w E10	5.01	4.11	29.39
Low Sulfur, w/o E10	14.79	0.86	54.12
Wtd average low sulfur	12.35	1.67	47.94
7 RVP, w E10	6.89	7.67	30.06
7 RVP, w/o E10	16.78	4.29	54.93
Wtd Average, 7 RVP	14.31	5.14	48.71
7 RVP w/T50, w/E10	7.73	7.70	30.84
7 RVP, w/T50, w/o E10	18.22	4.32	55.86
Wtd Average, 7 RVP w/ T50	15.60	5.17	49.61
No E10	16.78	4.29	54.93
100% E10	6.89	7.67	30.06

The percent changes in Table 23 are mostly positive, because the reference fuel for the Predictive Model is a California Phase 3 fuel. As noted in the table, the fuels that comes the closest to this reference fuel are the two California fuels, with and without ethanol. The reason they are not equivalent to the reference fuel is because we have altered the benzene level to be consistent with SEMCOG baseline gasoline.

Table 24. Exhaust Benefit of Gasoline Options Relative to SEMCOG Baseline Using Predictive Model - 2007 (%)			
Description	VOC	NOx	Toxics
Ca RFG	13.37	6.07	56.86
Ca RFG w/o E6	12.04	8.21	54.17
RFG	8.75	-1.34	68.95
RFG w/o E10	6.71	4.14	63.37
Lower Sulfur	2.29	3.65	1.51
7 RVP	0.00	0.00	0.00
7 RVP with T50	-1.51	-0.03	-1.74
No E10	-2.89	0.89	-12.12
100% E10	8.66	-2.67	36.37

Figure 2. Exhaust Emission Percent Benefits Using the Predictive Model



The California RFG with or without ethanol shows the greatest exhaust VOC and NOx reductions. The model indicates less of a VOC benefit, but a greater NOx benefit, for California RFG without ethanol as compared with ethanol. The Predictive Model indicates an exhaust VOC benefit and a small NOx disbenefit for RFG, but when ethanol is removed from RFG, there are both exhaust VOC and NOx reductions. Lower sulfur reduces both exhaust VOC and NOx emissions. Lower volatility is assumed to have no effect on exhaust VOC and NOx, but if the T50 levels increase, then exhaust VOC emissions increase. The no ethanol case shows an increase in VOC but a reduction in NOx; and the 100% E10 market share case shows a reduction in exhaust VOC but an increase in NOx.

5.3.3 Comparison of Complex and Predictive Model Results

A comparison of Complex and Predictive Model results for VOC and NOx, exhaust benefits, relative to SEMCOG baseline gasoline, is shown in Figures 3 and 4.[8]

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[7] A figure is not shown for toxics, because the Predictive and Complex models estimate toxics differently.

Figure 3. Comparison of Exhaust VOC Benefits

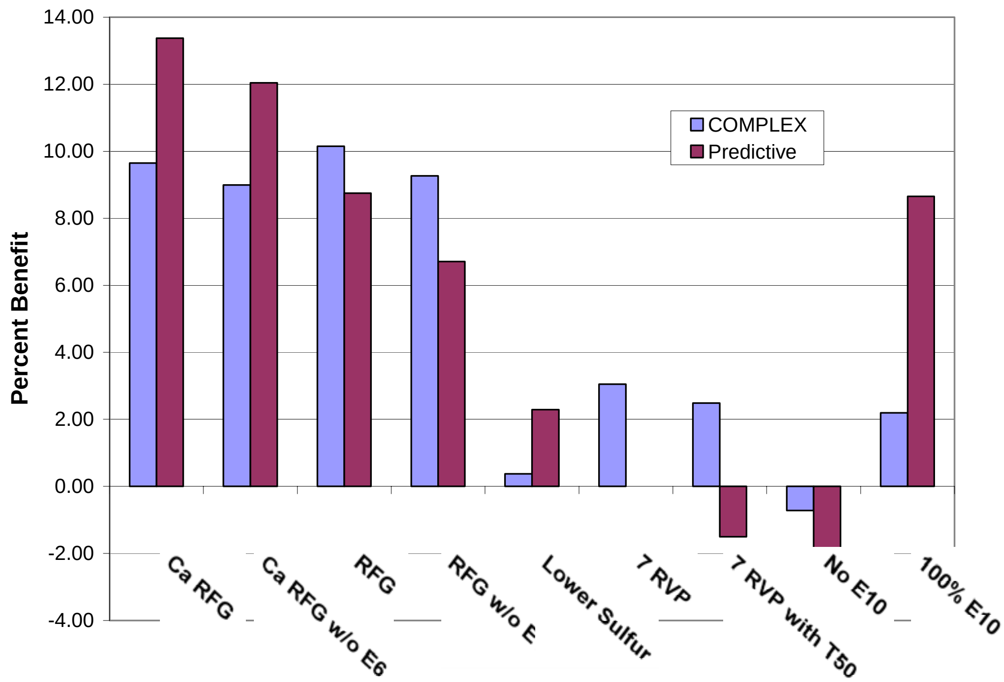
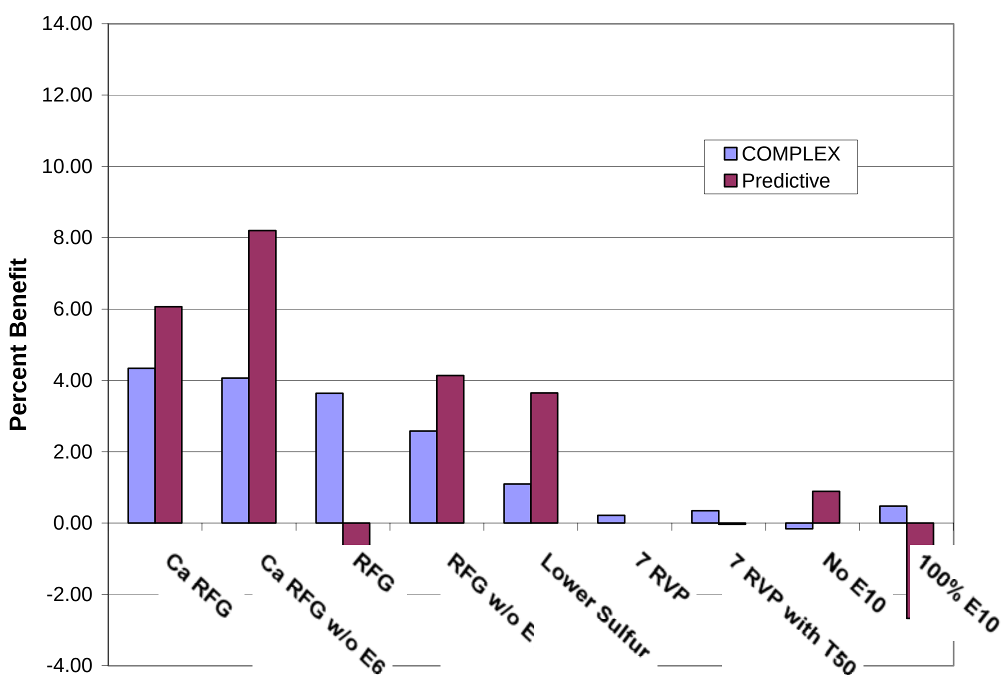


Figure 4. Comparison of NOx Benefits



In most cases, the two models show similar benefits, but in a few cases, the models show different results. The model results should not be "averaged." Generally, the Predictive Model contains more up-to-date sulfur effects, and improved statistical techniques. The Complex Model contains a more detailed analysis of fuel effects on high emitters than the Predictive Model.

Observations on the differences are presented below.

VOC

- The Predictive Model gives more credit to California RFG than the Complex Model, with or without ethanol. This is due to the Predictive Model including sulfur effects for advanced technology vehicles.

- The Predictive Model gives less credit to RFG with ethanol than the Complex model. The reason the Complex model benefit is higher is that the Complex model includes an explicit high emitter component, and ethanol is estimated to have more effect on high emitters than normal emitters. The Predictive Model also includes high emitters, but not in the same weighting as the Complex Model.

- The Predictive Model shows greater reduction for lower sulfur than Complex for the reasons mentioned earlier.

- The Predictive Model shows no exhaust benefits for 7 RVP fuel, and if the T50 temperature increases by 3ºF, then exhaust VOC is predicted to increase.

- The Predictive Model shows a much more significant reduction for 100% E10 than the Complex Model. This is due more to expected changes in T50 and T90 with ethanol, rather than the effects of ethanol at reducing emissions of high emitters.

NOx

- The Predictive Model shows greater reductions in NOx for California RFG and for lower sulfur, due to the increased sensitivity of this model to sulfur.

- The Predictive Model indicates that Federal RFG with ethanol and 100% E10 market share could increase NOx emissions, where the Complex model shows a small decrease in NOx for both cases

Overall, because the Predictive Model includes more up-to-date sulfur test data than the Complex model, the Predictive Model's results are probably more appropriate for the Southeastern Michigan gasoline fleet in the 2000-2010 timeframe.

This analysis of exhaust emissions benefits using both the Complex and Predictive Models should not be construed as providing definitive answers on expected State Implementation Plan (SIP) credits for these various fuel programs. This analysis provides a range of possible emission changes.

5.3.4 On-road Exhaust Inventory results

Exhaust VOC and NOx changes in summertime inventories utilizing both the Complex and Predictive Models are shown for calendar year 2007 in Figures 5 and 6. These reductions were estimated by multiplying the percent reductions in Figures 3 and 4 by the 2007 exhaust emission inventories from the SEMCOG region, shown with other calendar years in Table 25.

Table 25. Exhaust VOC and NOx Inventories in the SEMCOG Region for Gasoline Vehicles (passenger cars, light duty gasoline trucks, and heavy-duty gasoline vehicles), tons per summer day

Year	VOC	NOx
2002	103.7	197.1
2007	49.1	118.9
2010	38.3	89.5
2015	28.3	57.2
2020	24.5	41.7

For VOC, California RFG, with or without ethanol, shows inventory reductions of 4.5 to 6.5 tons per day (tpd). Federal RFG shows reductions of 3 to 5 tpd. Lower sulfur could reduce VOC by 1 tpd. The Complex model indicates that lower volatility could reduce exhaust VOC emissions by a little over 1 tpd, but the Predictive Model indicates no exhaust VOC benefit for volatility controls, and indicates that exhaust emissions could increase by over 1 tpd if T50 increases due to volatility controls. If ethanol is not used, both models indicate exhaust VOC would increase somewhat. If 100% E10 market share is used, the Complex model shows a small exhaust VOC benefit, but the Predictive Model shows a large exhaust VOC benefit. The Predictive Model exhaust VOC benefit is due more to the assumed T50 properties of a gasoline with ethanol, than the effect of ethanol on high emitters.

Figure 5. VOC Exhaust Inventory Reductions in 2007

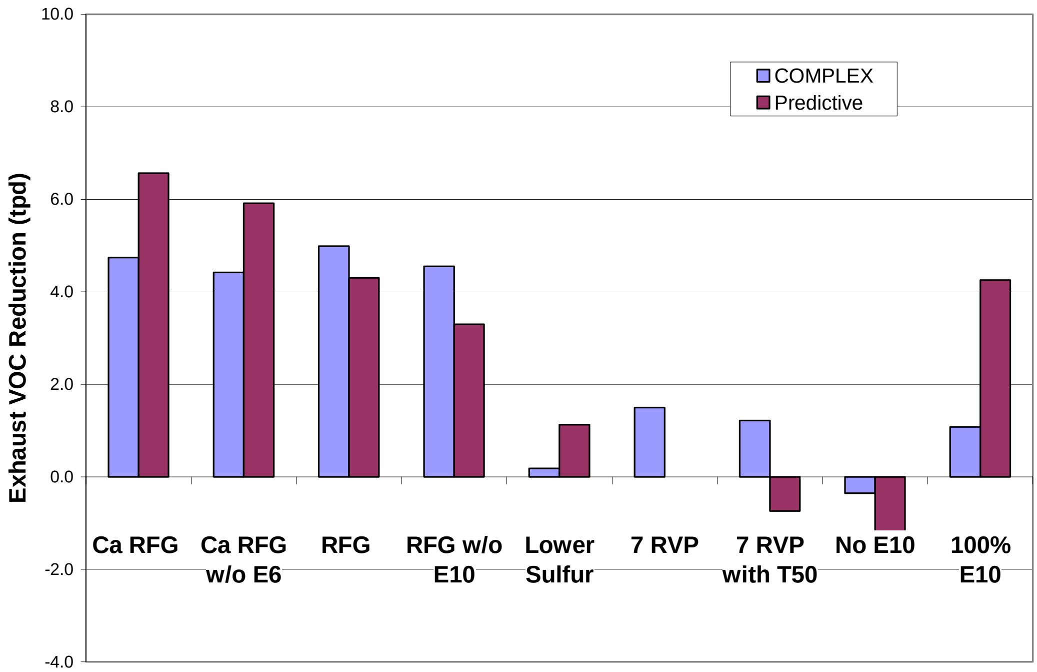
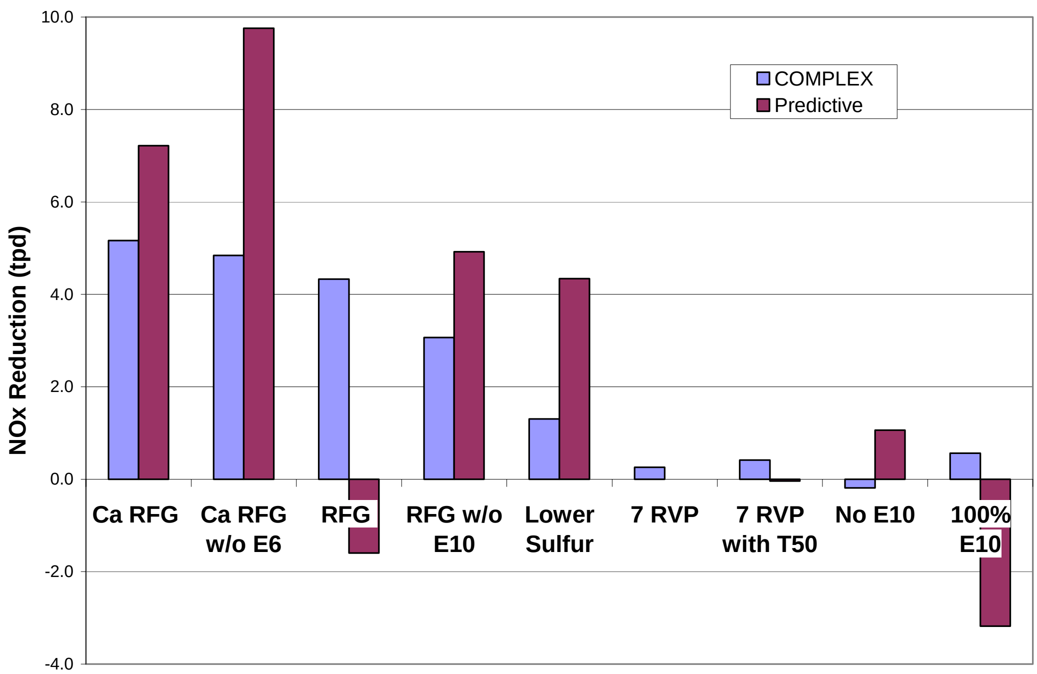


Figure 6. NOx Exhaust Inventory Reductions in 2007



For California RFG with or without ethanol, NOx emissions would be lower by 5-10 tpd. For Federal RFG with ethanol, the Complex Model indicates a 4.3 tpd decrease, the Predictive Model indicates a 1,6 tpd increase in NOx. The difference in NOx predictions is due to the Predictive Model's estimated effect at increasing NOx for 1988 and later vehicles when ethanol is included. This effect is also included in the CaRFG w/E6 prediction, but other parameters are changed in Ca RFG (like lower sulfur) that reduce NOx. Also, the Predictive Model indicates a 3 tpd NOx benefit loss to Ca RFG when ethanol is included. Lowering sulfur would reduce NOx by 1.5 to 4 tpd. The Predictive Model indicates that if ethanol is not used in Michigan, NOx emissions would be about 1 tpd lower. Increasing ethanol to 100% may increase NOx by 3 tpd.

Overall, the primary differences in the two exhaust models are:

- The Predictive Model gives more credit to lower sulfur control than the Complex model. This is due to more low sulfur data on advanced technology vehicles being included in this model, and the Predictive Model probably is more reliable on the issue of sulfur sensitivity.

- The Predictive Model increases NOx when ethanol is present, unless other parameters are significantly altered to mitigate the NOx increase (such as lower sulfur). As indicated in the Background section, EPA agrees there should be some NOx sensitivity for 1988-1995 vehicles, but does not yet agree whether the 1996+ vehicles are sensitive to ethanol content. Given that EPA agrees in some NOx sensitivity for 1988-1995 vehicles, there is probably some NOx increase for greater ethanol levels. However, both models indicate exhaust VOC is reduced with ethanol.

- The Predictive Model shows no exhaust benefit to reducing fuel volatility. This may not be a significant factor, because the main benefit in reducing volatility is to reduce evaporative VOC emissions. Whether or not there is an attendant exhaust VOC benefit may be somewhat inconsequential.

5.3.5 On-road evaporative results (excluding permeation due to ethanol)

The on-road evaporative benefits for the different proposals, excluding the permeation effect due to ethanol, are shown in Table 26. The size of the benefits is generally proportional to the size of the volatility changes.

Table 26. Evaporative Benefits of Gasoline Fuel Options (tons per summer day)				
Case	2007	2010	2015	2020
Ca RFG	6.2	4.7	3.2	2.6
Ca RFG w/o E6	4.5	3.4	2.3	1.9
RFG (both)	6.8	5.1	3.5	2.8
Low Sulfur	None			
7 RVP (both)	4.9	3.6	2.5	2.0
No E10	2.0	1.5	1.1	0.83
100% E10	-4.6	-3.5	-2.3	-1.9

The evaporative benefit of Ca RFG w/o E6 is less than Ca RFG because the volatility of this fuel (7.2) is estimated to be higher than with E6 (6.9). The 7 RVP benefit is lower than RFG, because this case assumes 25% of the gasoline has ethanol, with a 1 psi wavier. The 100% E10 market share case increases evaporative emissions due to the volatility waiver for ethanol.

5.4 Off-road results

Off-road inventory results are shown in Table 27. The VOC results include both exhaust and evaporative changes. The results change with changing ethanol content and RVP. The NONROAD model does not include evaporative emissions from portable containers. Emissions from portable containers would also be expected to decline with lower RVP.

Table 27. Benefits of Gasoline Options for Off-road Sources in 2007 (tons per summer day)				
Case	VOC	CO	NOx	SO_2
Ca RFG	2.1	177	-1.6	0.03
Ca RFG w/o E6	-0.2	-54	0.5	0.03
RFG	3.6	177	-1.6	0.0
RFG w/o E10	0.9	-54	0.5	0.0
Lower sulfur	0.0	0.0	0.0	0.03
Lower Volatility	0.7	0.0	0.0	0.0
0% E10	-0.6	-54	0.50	0.0
100% E10	1.9	177	-1.6	0.0

When ethanol penetration increases, CO is reduced, but NOx is increased. There are significant CO reductions with the use of ethanol. For the cases with 100% E10 market share, the CO reductions are 177 tpd. If ethanol were not used in Michigan, CO emissions from off-road sources would increase by 54 tpd. The lower sulfur and lower volatility cases show no CO changes because there is no change for the current ethanol market fraction (25%) for these cases.

The NONROAD model does not estimate the changes in direct PM from the different sulfur levels. However, it does estimate the change in SO_2. Table 27 shows the SO_2 reductions of Ca RFG and lower sulfur fuel.

5.5 Permeation Results

Table 28 shows the total permeation inventories in various years for on-road vehicles, off-road equipment, and portable containers for 100% E10 market share in the Southeast Michigan, as compared to no ethanol. The permeation inventory impact due to ethanol is 7.5 tpd, dropping to 6.4 tpd in 2020. These estimates assume no evaporative controls for off-road equipment or portable containers. EPA has already stated their intention of implementing an evaporative proposal for off-road equipment, so the ethanol permeation impact for off-road equipment will likely be reduced somewhat in the future.

The baseline estimated ethanol penetration in Michigan is 25%. Assuming this results in 25% of vehicles, equipment and portable containers containing a level of ethanol that would increase permeation emissions, the permeation emission increases for the baseline would be 25% of the values in Table 28.

Table 28. VOC Permeation Increases Assuming Ethanol in All Gasoline (tons per summer day)

Year	On-Road	Off-Road	Containers	Total
2002	4.4	1.0	2.2	7.6
2007	3.9	1.0	2.2	7.1
2010	2.9	1.1	2.4	6.4
2015	2.6	1.2	2.6	6.4
2020	2.3	1.3	2.8	6.4

Based on the results in Table 28, the permeation emissions for the various cases, including the baseline, are shown in Table 29 in calendar year 2007. The permeation VOC increases are a matter of ethanol market fraction for each case.

Table 29. Increased Permeation Emissions From Ethanol Associated with Various Fuels – 2007 (tons per summer day)					
Case	Ethanol Market Fraction	On-road	Off-road	Containers	Total
SEMCOG baseline gasoline	25%	1.0	0.25	0.6	1.85
Ca RFG	100%	3.9	1.0	2.2	7.1
Ca RFG w/o E6	0%	0.0	0.0	0.0	0.0
RFG	100%	3.9	1.0	2.2	7.1
RFG w/o E10	0%	0.0	0.0	0.0	0.0
Lower sulfur	25%	1.0	0.25	0.6	1.85
Lower Volatility (both)	25%	1.0	0.25	0.6	1.85
No E10	0%	0.0	0.0	0.0	0
100% E10	100%	3.9	1.0	2.2	7.1

Using the estimates in Table 29, the changes in permeation emission inventories relative to the SEMCOG baseline gasoline are shown in Table 30.

Table 30. Increases in Ethanol Permeation Emissions Relative to SEMCOG Baseline in 2007 (Tons per summer day)				
Case	On-road	Off-road	Containers	Total
Ca RFG	2.9	0.75	1.6	5.3
Ca RFG w/o E6	-1.0	-0.25	-0.6	-1.9
RFG	2.9	0.75	1.6	5.3
RFG w/o E10	-1.0	-0.25	-0.6	-1.9
Lower sulfur	0.0	0.0	0.0	0.0
Lower Volatility (both)	0.0	0.0	0.0	0.0
0% E10	-1.0	-0.25	-0.6	-1.9
100% E10	2.9	0.75	1.6	5.3

Results in Table 30 show a 5.3 tpd increase in permeation emissions for any of the 100% E10 market share cases. They also show a 2 tpd decrease in permeation emissions for no ethanol. Both the lower sulfur and lower volatility have no net change because those cases assume the same percent ethanol as the baseline.

5.6 Cumulative Benefits

The cumulative benefits as predicted by the Complex model for exhaust are shown in Table 31, and for the Predictive Model in Table 32. These emission benefits are estimated relative to the SEMCOG baseline gasoline. The tables show changes in emission of both on-road and off-road sources. The total cumulative benefits are also shown graphically for VOC + NOx in Figures 7 and 8.

Table 31. Cumulative Results for 2007 Relative to SEMCOG Baseline - Complex Model Used for On-Road Exhaust Emissions (tons per summer day)

	On-road			Off-road		All	Cumulative		
Case	Exhaust VOC	Evap VOC	NOx	VOC	NOx	Perm VOC	Total VOC	NOx	VOC + NOx
Ca RFG	4.7	6.2	5.2	2.1	-1.6	-5.3	7.7	3.6	11.3
Ca RFG w/o E6	4.4	4.5	4.8	-0.2	0.5	1.9	10.6	5.3	15.9
RFG	5.0	6.8	4.3	3.6	-1.6	-5.3	10.1	2.7	12.8
RFG w/o E10	4.6	6.8	3.1	0.9	0.5	1.9	14.2	3.6	17.8
Lower Sulfur	0.2	0.0	1.3	0.0	0.0	0.0	0.2	1.3	1.5
7 RVP	1.5	4.9	0.3	0.7	0.0	0.0	7.1	0.3	7.4
7 RVP with T50	1.2	4.9	0.4	0.7	0.0	0.0	6.8	0.4	7.2
No E10	-0.4	2.0	-0.2	-0.6	0.5	1.9	2.9	0.3	3.2
100% E10	1.1	-4.6	0.6	1.9	-1.6	-5.3	-6.9	-1.0	-7.91
7 RVP, no E10	1.1	6.9	0.1	0.1	0.5	1.9	10.0	0.6	10.6
7 RVP with T50, no E10	0.8	6.9	0.2	0.1	0.5	1.9	9.7	0.7	10.4

Table 32. Cumulative Results for 2007 Relative to SEMCOG Baseline – Predictive Model Used for On-Road Exhaust Emissions (tons per summer day)

	On-road			Off-road		All	Cumulative		
Case	Exhaust VOC	Evap VOC	NOx	VOC	NOx	Perm VOC	Total VOC	NOx	VOC + NOx
Ca RFG	6.6	6.2	7.2	2.1	-1.6	-5.3	9.6	5.6	15.2
Ca RFG w/o E6	5.9	5.9	9.8	-0.2	0.5	1.9	13.5	10.3	23.8
RFG	4.3	6.8	-1.6	3.6	-1.6	-5.3	9.4	-3.2	6.2
RFG w/o E10	3.3	6.8	4.9	0.9	0.5	1.9	12.9	5.4	18.3
Lower Sulfur	1.1	0.0	4.3	0.0	0.0	0.0	1.1	4.3	5.4
7 RVP	0	4.9	0.0	0.7	0.0	0.0	5.6	0.0	5.6
7 RVP with T50	-0.7	4.9	0.0	0.7	0.0	0.0	4.9	0.0	4.9
No E10	-1.4	2.0	1.0	-0.6	0.5	1.9	1.9	1.5	3.4
100% E10	4.3	-4.6	-3.2	1.9	-1.6	-5.3	-3.7	-4.7	-8.5
7 RVP, no E10	-1.4	6.9	1.0	0.1	0.5	1.9	7.5	1.5	9.0
7 RVP with T50, no E10	-2.1	6.9	1.0	0.1	0.5	1.9	6.8	1.5	8.3

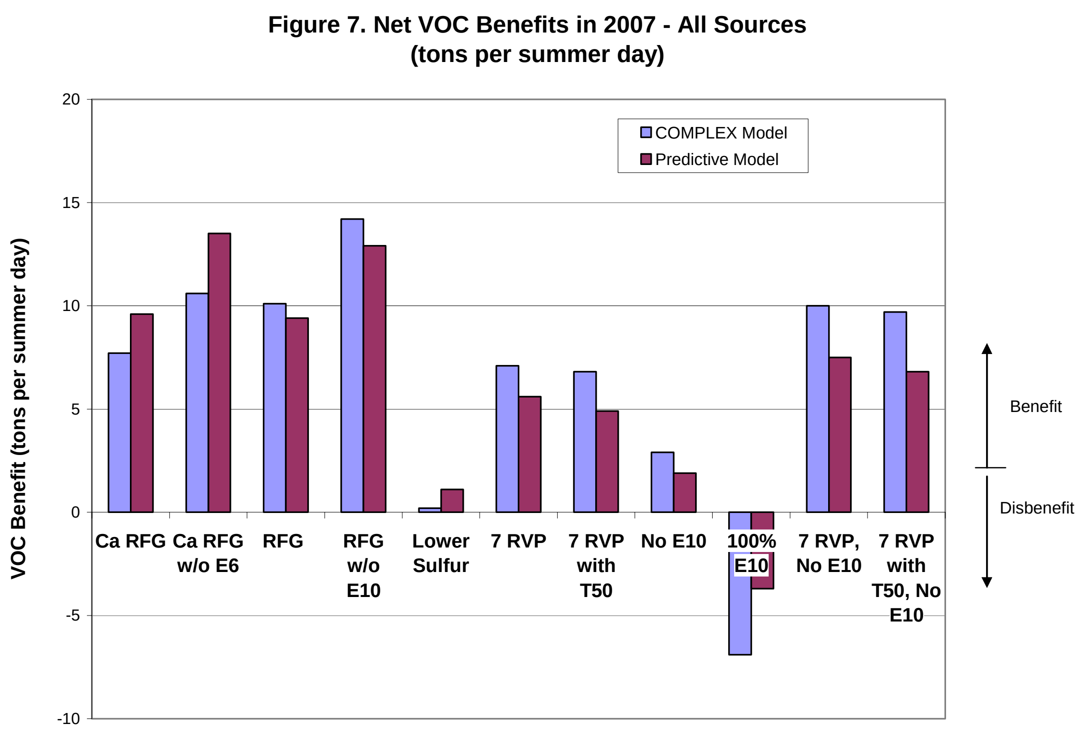


Figure 7. Net VOC Benefits in 2007 - All Sources
(tons per summer day)
VOC Benefit (tons per summer day)
20
15
10
5
0
-5
-10
COMPLEX Model
Predictive Model
Ca RFG
Ca RFG w/o E6
RFG
RFG w/o E10
Lower Sulfur
7 RVP
7 RVP with T50
No E10
100% E10
7 RVP, No E10
7 RVP with T50, No E10
Benefit
Disbenefit

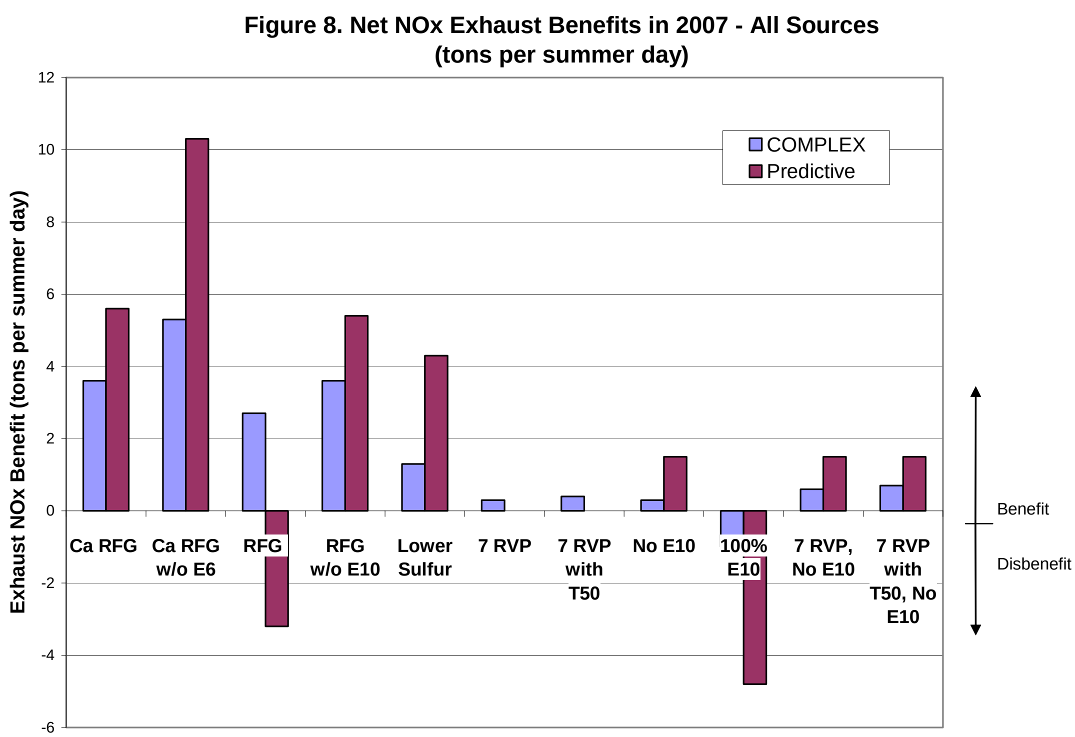


Figure 8. Net NOx Exhaust Benefits in 2007 - All Sources
(tons per summer day)
Exhaust NOx Benefit (tons per summer day)
12
10
8
6
4
2
0
-2
-4
-6
COMPLEX
Predictive
Ca RFG
Ca RFG w/o E6
RFG
RFG w/o E10
Lower Sulfur
7 RVP
7 RVP with T50
No E10
100% E10
7 RVP, No E10
7 RVP with T50, No E10
Benefit
Disbenefit

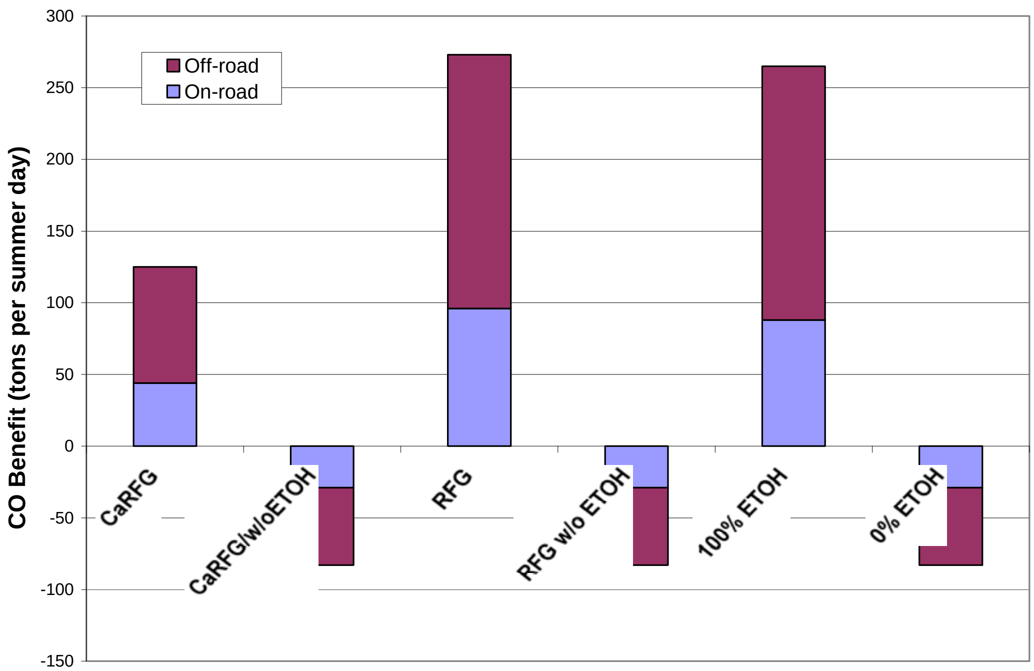
For VOC, the reformulated gasoline programs show the highest benefits. The benefits of the reformulated gasoline programs are less with ethanol than without, due to the increase in permeation VOC emissions due to ethanol. Lower volatility fuel also provides significant reductions. If the T50 level of lower volatility fuel increases, the Predictive Model indicates the overall benefit of lower volatility fuel is reduced. Finally, retaining the current gasoline program, and increasing the ethanol market fraction to 100% shows a significant VOC increase due to increased permeation VOC emissions and increased evaporative emissions under a 1 psi waiver.

For NOx, the benefits are highest for the two California RFG options. Both models indicate a higher NOx benefit without ethanol than with. The Predictive Model shows a NOx emission increase for Federal RFG with ethanol, but the Complex Model shows the opposite: a NOx decerase for Federal RFG with ethanol. Both Federal RFG without ethanol and lower sulfur show sizeable NOx benefits. Finally, the option that assumes a continuation of current Southeast Michigan gasoline but with 100% E10 market share (100% E10) shows a significant increase in NOx.

The VOC and NOx emission changes in Figures 7 and 8 for 7 RVP and lower sulfur fuel are additive. VOC emission reductions from 7 RVP and no ethanol are also largely additive, and would provide most of the VOC reductions projected from the RFG cases.

Net CO benefits are shown in Figure 9. Separate benefits are shown for on-road and off-road vehicles. Positive numbers are benefits, negative numbers are disbenefits. The CO benefits in this analysis are a function of ethanol content. Unfortunately, due to the lack of analytical models, the on-road CO benefits have not been adjusted for changes in fuel sulfur level, for low sulfur fuel and Ca RFG (with and without E6). If sulfur effects on CO were included, the benefits of the Ca RFG (with or without E6) would be greater than shown. Also, there would be some CO benefit for low sulfur fuel.

Figure 9. Net 2007 CO Benefits - All Sources



For PM, both the Ca RFG (with and without E6), and the Low Sulfur option would have some exhaust PM benefits.

5.6.1 Potential Benefit of RVP Reduction From 9.0 to 7.0 psi

While Southeast Michigan's summertime RVP limit is 7.8 psi, the remainder of the state, and many other parts of the Midwest have a 9.0 psi summer RVP limit. For this reason, the Michigan Department of Environmental Quality was interested in estimating evaporative emissions at 9 RVP, 7.8 RVP, and 7 RVP limits. Expected RVPs for these limits are 8.7, 7.6, and 6.8, respectively.

Table 33 shows total VOC, evaporative VOC, and CO emissions at expected RVPs for each of these three levels. The inventories are estimated for the SEMCOG region only.

Table 33. VOC and CO Inventories in SEMCOG Region at Different RVPs (tons per summer day)					
RVP	Pollutant	2007	2010	2015	2020
9 (8.7)	Total VOC	114.5	93.3	67.7	57.8
	Evap VOC	57.1	45.9	31.4	25.6
	CO	1319	1149	952	892
7.8 (7.6)	Total VOC	105.5	86.2	62.8	53.7
	Evap VOC	48.9	39.4	26.9	21.9
	CO	1257	1094	906	848
7.0 (6.8)	Total VOC	100.4	82.3	60.1	51.4
	Evap VOC	43.8	35.6	24.2	19.6
	CO	1257	1094	906	848

5.7 Diesel Programs

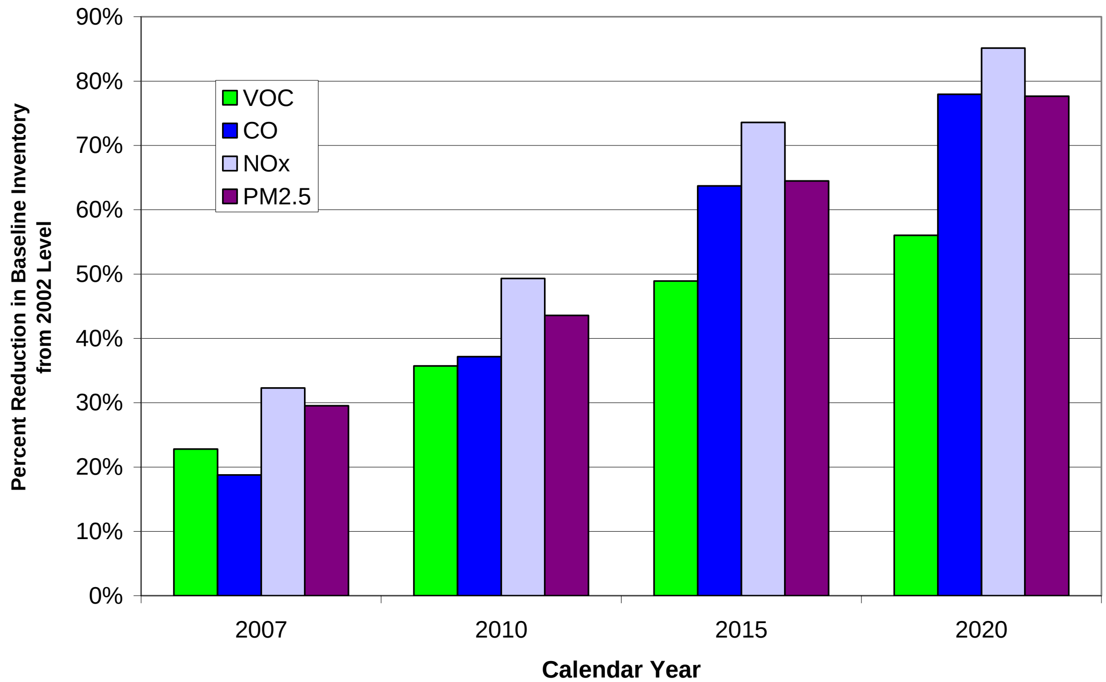
The following presents the inventory modeling results for the Baseline case followed by the analysis of the four diesel programs. All PM discussed in this section refers to PM2.5.

5.7.1 Baseline Diesel Inventory

The Baseline diesel emission inventory for the region is presented in Table 34. In 2002, the diesel sector is estimated to emit approximately 13 and 307 tons/day of VOC and NOx, respectively. The estimated impact of existing federal regulations is significant, and the diesel inventory is estimated to decline dramatically over time. By 2007, just five years later, the estimated diesel inventory is less than 2002 levels by 3 tons/day VOC and 99 tons/day NOx. It is important to consider the magnitude of these Baseline inventory reductions in the context of determining the need for any additional reductions achieved the proposed diesel programs. To illustrate the change in the total diesel inventory (both on-road and off-road), Figure 10 shows the percent change in the inventory relative to the 2002 Baseline. By 2010, reductions for all criteria pollutants are between 30 and 50 percent relative to 2002 levels.

Table 34. Baseline Diesel Inventory for Southeast Michigan (Tons per summer day)					
Calendar Year	Diesel Class	Emission Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-road	0.58	1.29	1.54	0.17
	Heavy-Duty On-road	7.84	43.59	262.65	5.17
	Light-Duty Off-road	0.73	2.54	2.89	0.43
	Heavy-Duty Off-road	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-road	0.35	0.94	0.93	0.08
	Heavy-Duty On-road	5.81	33.88	167.38	3.41
	Light-Duty Off-road	0.54	2.15	2.89	0.35
	Heavy-Duty Off-road	3.70	18.36	36.57	3.01
	Total Diesel	10.40	55.32	207.78	6.84
2010	Light-Duty On-road	0.10	0.20	0.21	0.02
	Heavy-Duty On-road	4.90	22.86	119.39	2.32
	Light-Duty Off-road	0.44	1.87	2.94	0.29
	Heavy-Duty Off-road	3.23	17.87	33.00	2.85
	Total Diesel	8.66	42.79	155.54	5.48
2015	Light-Duty On-road	0.12	0.55	0.20	0.02
	Heavy-Duty On-road	3.95	10.71	54.64	1.26
	Light-Duty Off-road	0.31	1.36	2.79	0.21
	Heavy-Duty Off-road	2.51	12.11	23.50	1.96
	Total Diesel	6.88	24.73	81.14	3.45
2020	Light-Duty On-road	0.08	0.50	0.12	0.02
	Heavy-Duty On-road	3.53	5.98	26.95	0.86
	Light-Duty Off-road	0.25	1.05	2.74	0.15
	Heavy-Duty Off-road	2.06	7.48	15.85	1.14
	Total Diesel	5.93	15.00	45.65	2.17

Figure 10. Baseline Inventory Reductions Relative to 2002 Level



5.7.2 Diesel Cetane Programs

The impacts of two diesel cetane programs were evaluated: a program that covers on-road diesel and a second that covers both on- and off-road diesel. For each, the cetane program results in an average cetane number of 50, where the increase in cetane number is achieved through cetane additives to the Baseline diesel fuel.

The per-vehicle emission impacts, based on the method and fuel properties described in Section 4.2.3, are presented in Table 35. As described in Section 4, off-road diesel is affected by the on-road program due to on-road diesel spillover into the off-road sector. The heavy-duty (HD) on-road impacts are model year specific to 2002-and-earlier model years. For 2003-and-later model year HD on-road engines are assumed to be unaffected by change in cetane as are light-duty (LD) on- and off-road engines.

Table 35. Estimated Change in Per Vehicle Emissions from Diesel Cetane Programs

Program Type	Fleet	Model Years	Calendar Years	HC	CO	NOx	PM
On-road Program	HD On-road	Pre-2003	All	-28.1%	-21.1%	-2.9%	-4.8%
	HD Off-road	All	2006-09	-10.3%	-7.3%	-1.0%	-1.7%
	HD Off-road	All	2010+	-9.8%	-7.0%	-1.0%	-1.6%
On- and Off-road Program	HD On-road	Pre-2003	All	-28.1%	-21.1%	-2.9%	-4.8%
	HD Off-road	All	2006-09	-31.4%	-23.5%	-3.3%	-5.7%
	HD Off-road	All	2010+	-28.1%	-21.1%	-2.9%	-4.8%

A sensitivity case was examined with respect to the estimated impacts of the cetane programs. The sensitivity case quantified the impact of a cetane program where half the increase in cetane number needed to reach 50 would be met through an increase in the natural cetane number (unadditized), with the remainder met though cetane additives. This resulted in a reduction in the NOx impact by 30 percent (e.g., from a -2.9 percent change for HD on-road to a -2.0 percent change).

This sensitivity case was evaluated at the request of stakeholder review, which suggested that the 7 to 9 increase in cetane number needed to reach 50 in Southeast Michigan might not be possible with additives alone. However, review of EPA resources and consultation with staff at the Office of Air Quality and Transportation suggest that a 10 to 15 increase in cetane number is possible through additives when the Baseline fuel has natural cetane levels as observed in this area. [27, 20] As such, we do not foresee this issue being critical to the success of the program, and we do not take these sensitivity results further than what is described here. Regardless, the results of this sensitivity analysis illustrate an important point, which is that the estimated benefits of cetane programs is sensitive to the natural cetane level of the Baseline fuel when following the EPA guidance methodology used in this study.

Table 36 presents the estimated emission inventory benefits of the on-road diesel cetane program, and Table 37 presents the results for the program that covers both on- and off-road fuels. In 2007, the on-road program is estimated to reduce VOC and NOx by approximately 1 and 4 tons/day, respectively. This increases to reductions of about 2 and 6 tons/day of VOC and NOx, respectively, for the on- and off-road program. Additional inventory results for criteria pollutants and toxic compounds are presented in Attachment B.

Table 36. Benefits from On-road Diesel Cetane Program (Ton per Summer Day)

Calendar Year	Diesel Class	Emission Inventory Benefit			
		VOC	CO	NOx	PM2.5
2007	Heavy-Duty On-road	1.03	4.46	3.40	0.11
	Heavy-Duty Off-road	0.38	1.34	0.36	0.05
	Total Diesel	1.41	5.79	3.76	0.16
2010	Heavy-Duty On-road	0.64	2.80	2.05	0.07
	Heavy-Duty Off-road	0.32	1.25	0.32	0.05
	Total Diesel	0.95	4.05	2.37	0.12
2015	Heavy-Duty On-road	0.26	0.96	0.84	0.03
	Heavy-Duty Off-road	0.25	0.85	0.22	0.03
	Total Diesel	0.50	1.81	1.06	0.06
2020	Heavy-Duty On-road	0.11	0.36	0.32	0.01
	Heavy-Duty Off-road	0.20	0.52	0.15	0.02
	Total Diesel	0.31	0.88	0.47	0.03

Table 37. Benefits from an On- and Off-road Diesel Cetane Program (Ton per Day Reduction from Baseline)					
Calendar Year	Diesel Class	Emission Inventory			
		VOC	CO	NOx	PM2.5
2007	Heavy-Duty On-road	1.03	4.46	3.40	0.11
	Heavy-Duty Off-road	1.16	4.31	1.19	0.17
	Total Diesel	2.19	8.76	4.59	0.28
2010	Heavy-Duty On-road	0.64	2.80	2.05	0.07
	Heavy-Duty Off-road	0.91	3.77	0.97	0.14
	Total Diesel	1.54	6.57	3.02	0.21
2015	Heavy-Duty On-road	0.26	0.96	0.84	0.03
	Heavy-Duty Off-road	0.70	2.55	0.69	0.09
	Total Diesel	0.96	3.51	1.52	0.12
2020	Heavy-Duty On-road	0.11	0.36	0.32	0.01
	Heavy-Duty Off-road	0.58	1.58	0.46	0.05
	Total Diesel	0.69	1.93	0.79	0.06

5.7.3 California Diesel Programs

The impacts of two California diesel programs were evaluated: a program that covers on-road diesel and a second that covers both on- and off-road diesel. For each, the California program requires specific diesel parameters to be met, or that a diesel fuel achieves an equivalent emissions reduction following California CARB guidelines. The results of this analysis are based on comparing the average properties of diesel sold in California versus those in the Baseline fuel of Southeast Michigan as described in Section 4.2.3.

The per-vehicle emission impacts are presented in Table 38. As already noted, off-road diesel is impacted by the on-road program due to on-road diesel spillover into the off-road sector. The heavy-duty (HD) on-road impacts are model year specific to 2002-and-earlier model years. For 2003-and-later model year HD on-road engines are assumed to be unaffected by the change in fuel properties assumed for the California program as are light-duty (LD) on-road engines. LD off-road engines realize a PM benefit due to reductions in average diesel sulfur content.

Table 38. Estimated Change in Per Vehicle Emissions from California Diesel Programs							
Program Type	Fleet	Model Years	Calendar Years	HC	CO	NOx	PM
On-road Program	HD On-road	Pre-2003	All	-27.2%	N/d	-8.6%	-10.2%
	HD Off-road	All	2006-09	-10.8%	N/d	-2.4%	-3.3%
	HD Off-road	All	2010+	-10.3%	N/d	-2.4%	-3.2%
	LD Off-road	All	2006-09	0.0%	0.0%	0.0%	-0.3%
On- and Off-road Program	HD On-road	Pre-2003	All	-27.2%	N/d	-8.6%	-10.2%
	HD Off-road	All	2006-09	-30.0%	N/d	-8.6%	-12.3%
	HD Off-road	All	2010+	-27.2%	N/d	-8.6%	-10.2%
	LD Off-road	All	2006-09	0.0%	0.0%	0.0%	-1.1%

A sensitivity case was examined with respect to the estimated impacts of the California program. The sensitivity case quantified the impact of a program where the Baseline aromatics content was assumed to equal 37 percent (compared to a Baseline of 39.3 percent assumed in the results shown above). The sensitivity case was evaluated at the request of stakeholder review, which suggested that aromatic content of the Baseline fuel may be reduced some by the 2007 timeframe for which the proposed program was evaluated. This sensitivity case only impacted the estimated PM emissions impact, of which the estimated PM benefits decreased by only 5 percent (95 percent of the estimated PM benefits remained). This level of impact is well within the uncertainty of the analysis, and this sensitivity case is not carried further in this analysis.

Table 39 presents the estimated emission inventory benefits of the on-road California diesel program, and Table 40 presents the results for the program that covers both on- and off-road fuels. In 2007, the on-road program is estimated to reduce VOC and NOx by approximately 1 and 11 tons/day, respectively. The benefits increase to about 2 and 13 tons/day of VOC and NOx, respectively, for the on- and off-road program. Additional inventory results for criteria pollutants and toxic compounds are presented in Attachment B. Notably in the case of HC-based toxic compounds, the estimated impacts are proportional to those estimated for HC exhaust.

Table 39. Benefit From On-road California Diesel Program (Ton per Day Reduction from Baseline)					
Calendar Year	Diesel Class	Emission Inventory Benefit			
		VOC	CO	NOx	PM2.5
2007	Heavy-Duty On-road	1.00	0.00	10.00	0.24
	Heavy-Duty Off-road	0.40	0.00	0.88	0.10
	Total Diesel	1.40	0.00	10.88	0.34
2010	Heavy-Duty On-road	0.62	0.00	6.04	0.15
	Heavy-Duty Off-road	0.33	0.00	0.79	0.09
	Total Diesel	0.95	0.00	6.83	0.24
2015	Heavy-Duty On-road	0.25	0.00	2.46	0.06
	Heavy-Duty Off-road	0.26	0.00	0.56	0.06
	Total Diesel	0.51	0.00	3.03	0.12
2020	Heavy-Duty On-road	0.10	0.00	0.95	0.02
	Heavy-Duty Off-road	0.21	0.00	0.38	0.04
	Total Diesel	0.31	0.00	1.33	0.06

Table 40. Benefit from On- and Off-road California Diesel Program (Ton per Day Reduction from Baseline)					
Calendar Year	Diesel Class	Emission Inventory Benefit			
		VOC	CO	NOx	PM2.5
2007	Heavy-Duty On-road	1.00	0.00	10.00	0.24
	Heavy-Duty Off-road	1.11	0.00	3.15	0.37
	Total Diesel	2.11	0.00	13.15	0.61
2010	Heavy-Duty On-road	0.62	0.00	6.04	0.15
	Heavy-Duty Off-road	0.88	0.00	2.84	0.29
	Total Diesel	1.49	0.00	8.88	0.44
2015	Heavy-Duty On-road	0.25	0.00	2.46	0.06
	Heavy-Duty Off-road	0.68	0.00	2.02	0.20
	Total Diesel	0.93	0.00	4.48	0.26
2020	Heavy-Duty On-road	0.10	0.00	0.95	0.02
	Heavy-Duty Off-road	0.56	0.00	1.36	0.12
	Total Diesel	0.66	0.00	2.31	0.14

5.7.4 Biodiesel Programs

The impacts of two biodiesel programs were evaluated: a 5 percent on-road biodiesel program and a 20 percent on-road biodiesel program. Because EPA guidelines found the impacts of biodiesel on emissions from off-road engines to be inconclusive, the impacts of a biodiesel program for the off-road sector were not examined. [29]

The per-vehicle emission impacts are presented in Table 41. Note that NOx emissions are estimated to increase with biodiesel as shown by the values greater than zero. There were insufficient data to estimate an impact on the LD on-road sector, and none is modeled in this study.

Table 41. Estimated Change in Per Vehicle Emissions from Biodiesel Programs

Program Type	Fleet	Model Years	Calendar Years	HC	CO	NOx	PM
5% On-road Program	HD On-road	All	All	-5.4%	-3.2%	0.5%	-3.1%
20% On-road Program	HD On-road	All	All	-20.1%	-12.3%	2.0%	-12.0%

The biodiesel data for HC-based toxic compounds show that these compounds do not change in proportion to the HC exhaust change,[9] and specific reductions for individual compounds are presented in Table 42. For acrolein, 1,3-butadiene and benzene, the data are inconclusive and no change in emissions is assumed. [29]

Table 42. Estimated Change in Per Vehicle Toxic Compound Emissions from Biodiesel Programs

Program Type	Fleet	Model Years	Calendar Years	Acetaldehyde	Formaldehyde
5% On-road Program	HD On-road	All	All	-0.8%	-0.8%
20% On-road Program	HD On-road	All	All	-3.2%	-3.4%

Table 43 presents the estimated emission inventory benefits of both the 5 percent and 20 percent biodiesel programs. In 2007, the 5 percent biodiesel program is estimated to reduce VOC by 0.3 tons/day and increase NOx by 0.8 tons/day. Under the 20 percent program, the 2007 impacts are a 1.2 ton/day VOC reduction and a 3.4 tons/day NOx increase. Note that for the biodiesel programs, all benefits are realized by the HD on-road sector (no other sectors of the diesel inventory are impacted). Additional inventory results for criteria pollutants and toxic compounds are presented in Attachment B.

[9] For the other three types of diesel programs studies, HC-based toxic compounds impacts are generally proportional to the change in HC exhaust.

Table 43. Benefit from On-road 5 and 20 Percent Biodiesel Programs (Ton per Day Reduction from Baseline)					
Calendar Year	Biodiesel Program	Emission Inventory Benefit			
		VOC	CO	NOx	PM2.5
2007	5 Percent Biodiesel	0.31	1.08	-0.84	0.11
	20 Percent Biodiesel	1.17	4.17	-3.35	0.41
2010	5 Percent Biodiesel	0.26	0.73	-0.60	0.07
	20 Percent Biodiesel	0.98	2.81	-2.39	0.28
2015	5 Percent Biodiesel	0.21	0.34	-0.27	0.04
	20 Percent Biodiesel	0.79	1.32	-1.09	0.15
2020	5 Percent Biodiesel	0.19	0.19	-0.13	0.03
	20 Percent Biodiesel	0.71	0.74	-0.54	0.10

5.7.5 Diesel Retrofit Programs

Three levels of diesel retrofit programs were examined, which are defined by the emissions control achieved by the retrofit devices. These levels were defined by the natural groupings of similar technologies found in the EPA and CARB certification data. At the time of this study, technologies have been certified almost exclusively for the HD on-road sector, and only the impacts on the HD on-road sector were examined. The per-vehicle emission impacts, defined by the retrofit level, are presented in Table 44.

Table 44. Estimated Change in Per Vehicle Emissions from Diesel Retrofits					
Retrofit Level	Applicable Engines	HC	CO	NOx	PM
Level 1	1991 – 2002 model year HD on-road	-40%	-40%	0%	-20%
Level 2	1994 – 2002 model year HD on-road	-60%	-60%	0%	-60%
Level 3	1994 – 2002 model year HD on-road	-75%	-75%	0%	-85%

Table 45 presents the estimated emission inventory benefits of the three levels of diesel retrofit programs. In 2007, the Level 1, 2 and 3 programs are estimated to achieve reductions in VOC emissions equal to 1.1, 1.4 and 1.7 tons/day, respectively. There is no impact on diesel NOx emissions. Additional inventory results for criteria pollutants and toxic compounds are presented in Attachment B.

Table 45. Benefit from On-road Diesel Retrofit Program (Ton per Day Reduction from Baseline)					
Calendar Year	Retrofit Level	Emission Inventory Benefit			
		VOC	CO	NOx	PM2.5
2007	Level 1	1.06	5.32	0.00	0.49
	Level 2	1.39	6.77	0.00	0.53
	Level 3	1.74	8.47	0.00	0.75
2010	Level 1	0.68	3.40	0.00	0.32
	Level 2	0.89	4.35	0.00	0.34
	Level 3	1.11	5.43	0.00	0.48
2015	Level 1	0.36	1.82	0.00	0.24
	Level 2	0.42	1.99	0.00	0.18
	Level 3	0.52	2.49	0.00	0.25
2020	Level 1	0.15	0.68	0.00	0.08
	Level 2	0.23	1.02	0.00	0.12
	Level 3	0.28	1.27	0.00	0.17

Note that the retrofit program benefits reported here assume 100 percent implementation (see Section 4.2.2 for a further discussion of program implementation assumptions including a discussion of program coverage). In the case of diesel retrofits, achieving 100 percent coverage of all vehicles operating in the region is not realistic, whereas for the other three diesel program types that target the diesel fuel marketed, 100 percent implementation is nearly achievable. Scaling these results to a target implementation rate can be easily completed as the reported benefits are a linear function of the implementation rate. However, actual retrofit programs may target a specific fleet (of known vehicle classes with known operating characteristics) for which estimating the benefits from these results are not straightforward. To facilitate a vehicle-specific analysis, the diesel retrofit benefits reported on a per-vehicle basis are provided in Attachment C to this report.

5.7.6 Summarized Results

Figure 11 summarizes the inventory benefits of the diesel programs on VOC, CO and NOx emissions in 2007. VOC benefits range from 0.3 tons/day for the 5 percent biodiesel program to just over 2 tons/day for the cetane and California diesel programs that cover both on- and off-road fuels. NOx benefits range from about -3 tons/day (an increase in NOx) for the 20 percent biodiesel program to about a 13 ton/day reduction estimated for the on- and off-road California diesel program.

Figure 11. Summary of Inventory Benefits of Diesel Programs HC,CO and NOx in 2007

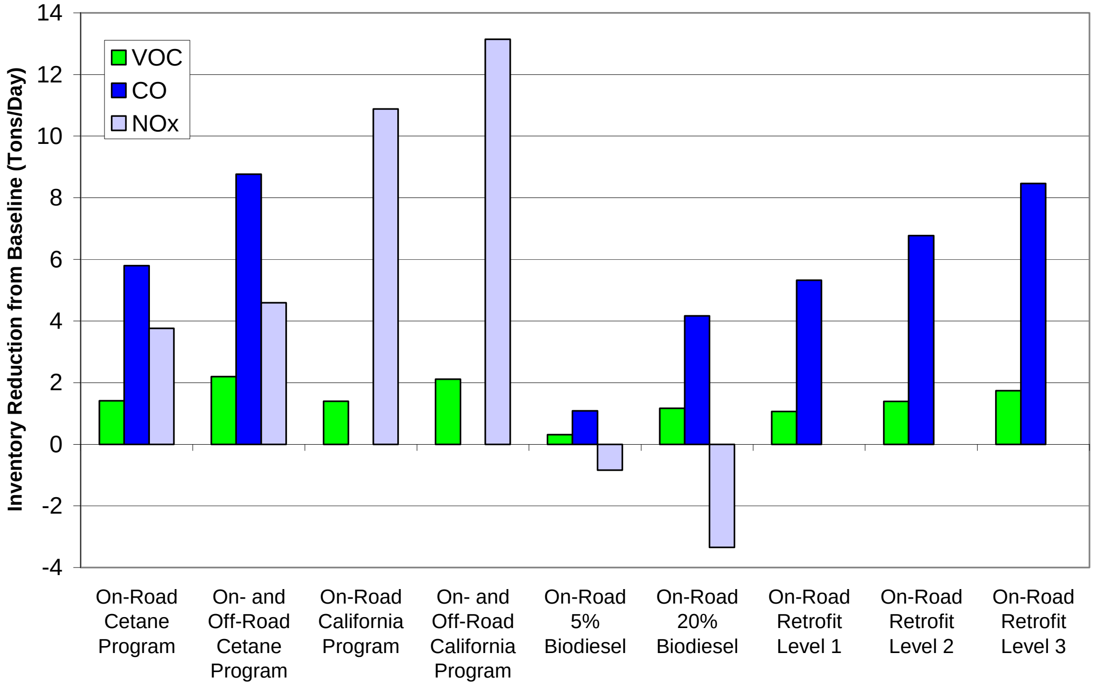


Figure 12 summarizes the inventory benefits of the diesel programs on VOC, CO and NOx emissions in 2010. The scale of this figure is the same as Figure 10 to facilitate comparisons. Notably, the emissions benefits of the diesel programs decline with time which is visibly apparent from comparing these two figures. The decline in benefit over time is driven by two factors, the reduction in the Baseline inventory over time and the reduction in activity of targeted model year groups (which will tend to be operating less with increasing age).

Figure 12. Summary of Inventory Benefits of Diesel Programs HC,CO and NOx in 2010

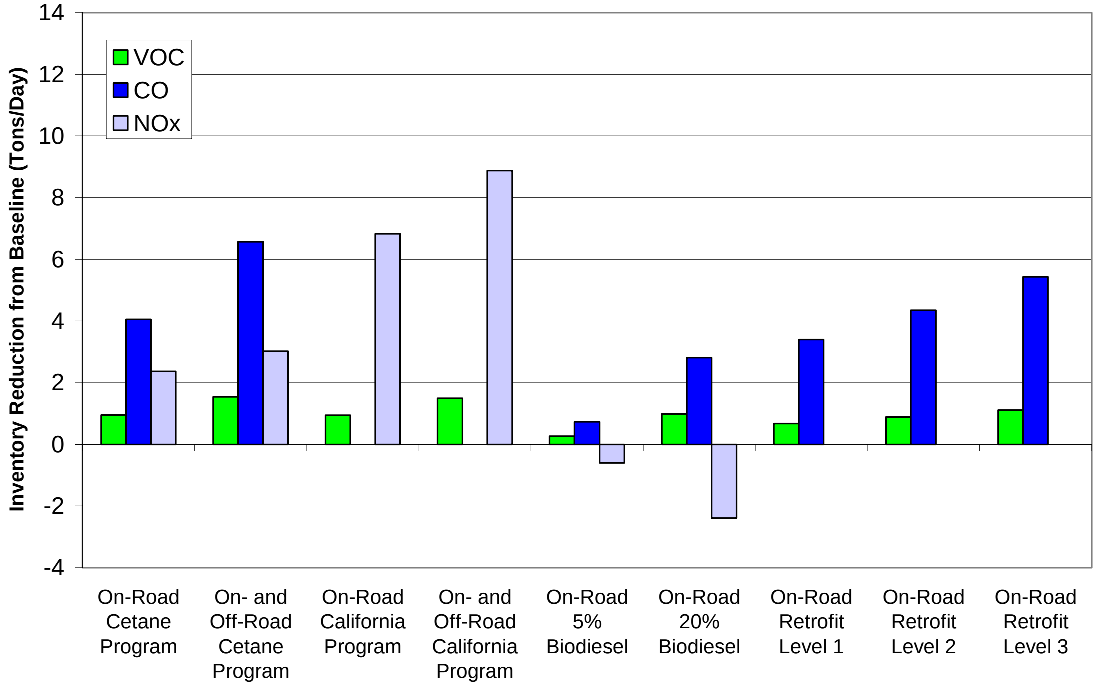
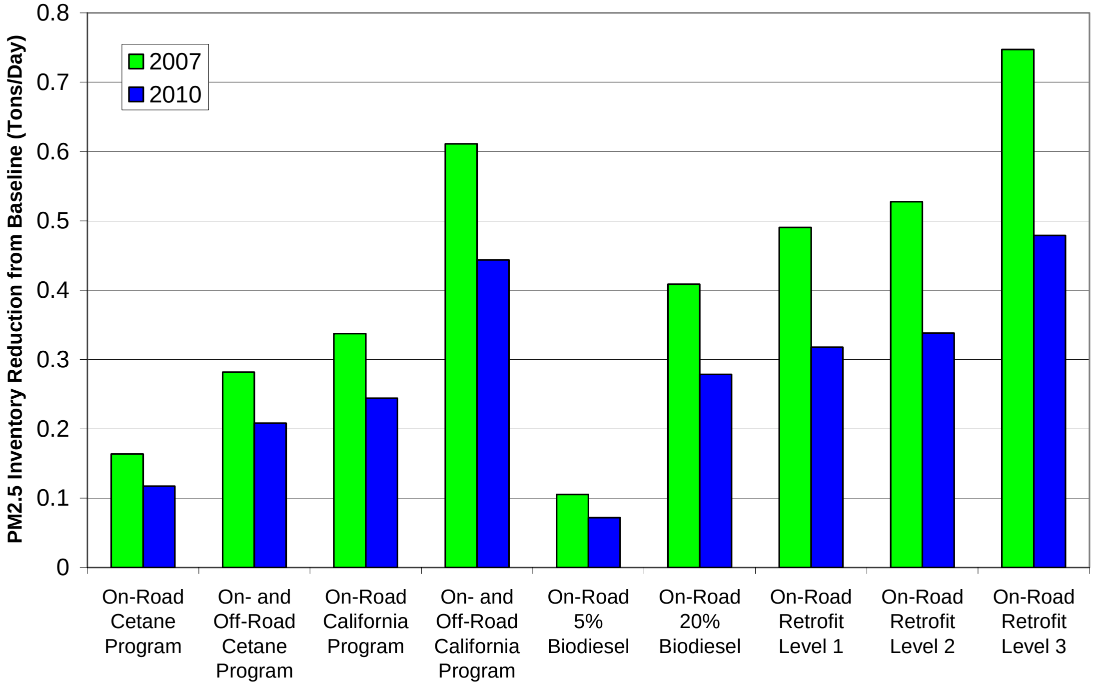


Figure 13 summarizes the 2007 and 2010 inventory benefits for directly emitted PM2.5 exhaust emissions. Benefits range from about 0.1 to 0.8 tons/day depending on the program. As with VOC, CO and NOx, the benefits reported in tons/day decline over time as the fleet turns over.

Figure 13. Summary of Inventory Benefits of Diesel Programs PM2.5 in 2007 & 2010



6.0 Discussion

This section discusses primary sources of uncertainty in the emissions inventory analysis.

6.1 Gasoline Options

Complex vs Predictive Model – The Complex and Predictive Models differ in the magnitude and sometimes direction of the benefit predicted. As indicated in this study, the Predictive Model has been updated with more sulfur data than the Complex model, and utilizes more sophisticated modeling techniques than the earlier generation Complex Model. Although both models could use a lot more data, the Predictive Model is probably a more advanced model, and therefore should be relied on preferentially over the Complex Model.

Expected Gasoline Properties – This emission inventory study determined likely post-sulfur control fuel properties for a variety of gasoline options. The resulting emission benefits depended on these fuel properties. While we tried to follow a clear rationale for picking these properties, in the final analysis they could be significantly different than what was predicted in this study, and this could affect the emission benefits of the options.

Ethanol Permeation Effects – This report utilized ethanol permeation effects from a study conducted by AIR for the API. The CARB recently conducted a preliminary study of ethanol permeation effects in California. In their study, the CARB determined that ethanol increased permeation emissions in the South Coast Air Basin by about 19 tpd for on-road vehicles. AIR's estimate for on-road vehicles in the South Coast was 7 tpd. While AIR has conducted a review of CARB's methods, and determined that the effect as estimated by AR is reasonable, this nonetheless illustrates the uncertainty associated with the permeation inventory – the ethanol permeation impacts could be higher than we have estimated. Also, the permeation effects are based on tests with E6. On E10, the permeation emissions could be higher.

Effects of Ethanol on NOx Emissions – The Complex model shows little effect of ethanol on NOx, the Predictive Model, however, estimates that NOx increases when ethanol is used. EPA and CARB agree that there is an increase in NOx emissions for 1988-1995 vehicles; the Predictive Model also estimates and increase for 1996+ vehicles. The Coordinating Research Council is completing more testing of ethanol effects on LEVs which should help to answer the question of the NOx effects for 1996 and later light duty vehicles and trucks.

Ethanol CO Effects – Ethanol reduces CO emissions from on-road vehicles and off-road gasoline equipment. CO does contribute to ozone formation, although its reactivity is much lower than most of the VOC species. With a waiver, ethanol increases evaporative VOC emissions. It also increases permeation VOC emissions. It is not clear whether the

CO reductions compensate for the increase in VOC permeation emissions. SEMCOG and others may perform ozone modeling to answer this question in the near future.

Lower RVP Effects on Off-Road Sources – The NONROAD model's evaporative emissions are in the process of being updated by the EPA. Currently, there are no hot soak emissions, running losses, or resting losses included in the model. The model also does not include portable containers used to refuel gasoline equipment. The model does not account for the reduction in evaporative emissions from both off-road equipment and portable containers due to lower fuel volatility. Thus, the benefits of lower fuel volatility are higher than estimated in this study.

6.2 Diesel Options

50 Cetane – The emissions effect of higher cetane follows EPA's guidance, and we assume that the 50 cetane level can be achieved through cetane additives. The effect is applied to non-EGR vehicles (2002 and earlier), and light duty diesels are assumed to have no emissions response to cetane. Sources of uncertainty include EPA's emission reductions vs cetane levels, the possibility of a light duty vehicle emissions response, and the extent of spillover into off-road applications of on-road fuel.

CARB Diesel – Emission benefits were estimated using EPA guidance and the difference in baseline and predicted diesel fuel parameters. Similar to the gasoline options, if the predicted fuel composition is not correct, then the emission benefits will be different than estimated. Benefits apply only to 2002 and earlier non-EGR engines. The extent of spillover into off-road applications is another factor affecting these benefits.

Biodiesel – The benefits follow EPA's guidance, and this guidance is several years old: much more testing data has become available, and the guidance is probably out of date. Another issue is the market share of biodiesel. Our emission reductions assume 100% coverage in the SEMCOG area, if the market fraction is lower then the benefits can be scaled.

PM Retrofits – We estimate reductions for three basic levels of PM control – 20%, 60%, and 80%. The PM benefits depend on how many vehicles can actually be equipped with the devices, whether they have the same activity as the MOBILE6.2 model assumes, and the durability of the PM devices. Our assumption is that they do not deteriorate; that the 20%, 60%, and 80% reductions apply for the remainder of each vehicle's life. We have also made certain assumptions about the HC, and CO reductions accompanying the PM reductions. If these are different than our estimates, than the overall emissions benefits will be different.

7.0 References

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Attachment A
Example Calculation of Percent Benefits from SEMCOG Baseline Gasoline

The following example estimates the percent reduction of No Toxics Ca RFG relative to SEMCOG baseline gasoline, utilizing the percent reductions of both fuels relative to the Clean Air Act baseline gasoline.

The "fuel factor" is the percent reduction of the control gasoline relative to the SEMCOG baseline, and is estimated with the following equation:

Fuel Factor = (% Reduction of Control Fuel Relative to Reference Fuel - % Reduction of SEMCOG Baseline Relative to Reference Fuel)/(1+ % Reduction of SEMCOG Baseline Relative to Reference Fuel)

Complex Model results of No Toxics Ca RFG for VOC:

% Reduction of SEMCOG wtd. avg. Baseline vs CAA Baseline: -8.47%*
% Reduction of No Toxics Ca RFG vs CAA Baseline: -17.30% (Table 14)

% Reduction of No Toxics Ca RFG relative to SEMCOG:

(-17.3-(-8.47))/(1-0.0847) = -8.83/0.9153 = 9.65%

Thus, in this example, No Toxics Ca RFG results in 9.65% lower VOC emissions than SEMCOG Baseline.

* Table 14, weighted average of baseline with ETOH (25%) and baseline without ETOH (75%)

Attachment B – Additional Diesel Program Inventory Results

This Attachment contains additional tabulated inventory results for the diesel program control measures referred to in Section 5.7 of this report. The contents are as follows.

- Table B-1. On-road Diesel Cetane Program Criteria Pollutant Inventory (Tons/Day)
- Table B-2. On-road Diesel Cetane Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-3. On-road Diesel Cetane Program Toxic Species Inventory (Percent Reduction)

- Table B-4. On- and Off-road Diesel Cetane Program Criteria Pollutant Inventory (Tons/Day)
- Table B-4. On- and Off-road Diesel Cetane Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-6. On- and Off-road Diesel Cetane Program Toxic Species Inventory (Percent Reduction)

- Table B-7. On-road California Diesel Program Criteria Pollutant Inventory (Tons/Day)
- Table B-8. On-road California Diesel Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-9. On-road California Diesel Program Toxic Species Inventory (Percent Reduction)

- Table B-10. On- and Off-road California Diesel Program Criteria Pollutant Inventory (Tons/Day)
- Table B-11. On- and Off-road California Diesel Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-12. On- and Off-road California Diesel Program Toxic Species Inventory (Percent Reduction)

- Table B-13. On-road 5% Biodiesel Program Criteria Pollutant Inventory (Tons/Day)
- Table B-14. On-road 5% Biodiesel Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-15. On-road 5% Biodiesel Program Toxic Species Inventory (Percent Reduction)

- Table B-16. On-road 20% Biodiesel Program Criteria Pollutant Inventory (Tons/Day)
- Table B-17. On-road 20% Biodiesel Program Criteria Pollutant Inventory (Percent Reduction)

- Table B-18. On-road 20% Biodiesel Program Toxic Species Inventory (Percent Reduction)

- Table B-19. On-road Level 1 Diesel Retrofit Program Criteria Pollutant Inventory (Tons/Day)
- Table B-20. On-road Level 1 Diesel Retrofit Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-21. On-road Level 1 Diesel Retrofit Program Toxic Species Inventory (Percent Reduction)

- Table B-21. On-road Level 2 Diesel Retrofit Program Criteria Pollutant Inventory (Tons/Day)
- Table B-22. On-road Level 2 Diesel Retrofit Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-23. On-road Level 2 Diesel Retrofit Program Toxic Species Inventory (Percent Reduction)

- Table B-24. On-road Level 3 Diesel Retrofit Program Criteria Pollutant Inventory (Tons/Day)
- Table B-25. On-road Level 3 Diesel Retrofit Program Criteria Pollutant Inventory (Percent Reduction)
- Table B-26. On-road Level 3 Diesel Retrofit Program Toxic Species Inventory (Percent Reduction)

Table B-1. On-Highway Diesel Cetane Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.84	38.33	170.79	3.52
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	4.09	19.70	36.93	3.06
	Total Diesel	11.82	61.11	211.54	7.01
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.53	25.66	121.45	2.39
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.54	19.12	33.32	2.89
	Total Diesel	9.61	46.85	157.91	5.60
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.20	11.67	55.47	1.29
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.75	12.95	23.73	1.99
	Total Diesel	7.38	26.53	82.20	3.51
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.64	6.34	27.27	0.87
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.27	8.00	16.00	1.16
	Total Diesel	6.23	15.88	46.13	2.20

Table B-2. On-Highway Diesel Cetane Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.8%	13.2%	2.0%	3.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	7.3%	1.0%	1.7%
	Total Diesel	13.6%	10.5%	1.8%	2.4%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.0%	12.3%	1.7%	3.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	9.8%	7.0%	1.0%	1.6%
	Total Diesel	11.0%	9.5%	1.5%	2.1%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.5%	8.9%	1.5%	2.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	9.8%	7.0%	1.0%	1.6%
	Total Diesel	7.3%	7.3%	1.3%	1.7%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.0%	6.0%	1.2%	1.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	9.8%	7.0%	1.0%	1.6%
	Total Diesel	5.2%	5.9%	1.0%	1.3%

Table B-3. On-Highway Diesel Cetane Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.8%	17.8%	17.8%	17.8%	17.8%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	10.3%	10.3%	10.3%	10.3%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.0%	13.0%	13.0%	13.0%	13.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	9.8%	9.8%	9.8%	9.8%	9.8%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.5%	6.5%	6.5%	6.5%	6.5%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	9.8%	9.8%	9.8%	9.8%	9.8%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.0%	3.0%	3.0%	3.0%	3.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	9.8%	9.8%	9.8%	9.8%	9.8%

Table B-4. On- and Off-Highway Diesel Cetane Program Diesel Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.84	38.33	170.79	3.52
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	4.87	22.67	37.76	3.18
	Total Diesel	12.60	64.08	212.37	7.13
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.53	25.66	121.45	2.39
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	4.13	21.63	33.97	2.98
	Total Diesel	10.20	49.36	158.56	5.69
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.20	11.67	55.47	1.29
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	3.21	14.66	24.19	2.05
	Total Diesel	7.84	28.24	82.66	3.57
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.64	6.34	27.27	0.87
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.64	9.06	16.31	1.20
	Total Diesel	6.61	16.93	46.44	2.24

Table B-5. On- and Off-Highway Diesel Cetane Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.8%	13.2%	2.0%	3.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	31.4%	23.5%	3.3%	5.7%
	Total Diesel	21.1%	15.8%	2.2%	4.1%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.0%	12.3%	1.7%	3.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	28.1%	21.1%	2.9%	4.8%
	Total Diesel	17.8%	15.3%	1.9%	3.8%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.5%	8.9%	1.5%	2.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	28.1%	21.1%	2.9%	4.8%
	Total Diesel	14.0%	14.2%	1.9%	3.5%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.0%	6.0%	1.2%	1.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	28.1%	21.1%	2.9%	4.8%
	Total Diesel	11.6%	12.9%	1.7%	3.0%

Table B-6. On- and Off-Highway Diesel Cetane Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.8%	17.8%	17.8%	17.8%	17.8%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	31.4%	31.4%	31.4%	31.4%	31.4%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.0%	13.0%	13.0%	13.0%	13.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	28.1%	28.1%	28.1%	28.1%	28.1%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.5%	6.5%	6.5%	6.5%	6.5%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	28.1%	28.1%	28.1%	28.1%	28.1%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.0%	3.0%	3.0%	3.0%	3.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	28.1%	28.1%	28.1%	28.1%	28.1%

Table B-7. On-Highway California Diesel Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.81	33.88	177.38	3.64
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	4.10	18.36	37.45	3.11
	Total Diesel	11.80	55.32	218.66	7.18
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.51	22.86	125.43	2.48
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.56	17.87	33.79	2.94
	Total Diesel	9.61	42.79	162.37	5.72
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.20	10.71	57.10	1.32
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.77	12.11	24.07	2.02
	Total Diesel	7.39	24.73	84.16	3.57
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.64	5.98	27.90	0.88
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.28	7.48	16.23	1.18
	Total Diesel	6.24	15.00	46.98	2.23

Table B-8. On-Highway California Diesel Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.2%	0.0%	6.0%	7.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.3%
	Heavy-Duty Off-Highway	10.8%	0.0%	2.4%	3.3%
	Total Diesel	13.4%	0.0%	5.2%	4.9%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	12.6%	0.0%	5.1%	6.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	0.0%	2.4%	3.2%
	Total Diesel	11.0%	0.0%	4.4%	4.5%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.3%	0.0%	4.5%	4.8%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	0.0%	2.4%	3.2%
	Total Diesel	7.4%	0.0%	3.7%	3.6%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	2.9%	0.0%	3.5%	2.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	0.0%	2.4%	3.2%
	Total Diesel	5.3%	0.0%	2.9%	2.6%

Table B-9. On-Highway California Diesel Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.2%	17.2%	17.2%	17.2%	17.2%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.8%	10.8%	10.8%	10.8%	10.8%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	12.6%	12.6%	12.6%	12.6%	12.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	10.3%	10.3%	10.3%	10.3%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.3%	6.3%	6.3%	6.3%	6.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	10.3%	10.3%	10.3%	10.3%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	2.9%	2.9%	2.9%	2.9%	2.9%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	10.3%	10.3%	10.3%	10.3%	10.3%

Table B-10. On- and Off-Highway California Diesel Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.81	33.88	177.38	3.64
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	4.81	18.36	39.72	3.38
	Total Diesel	12.51	55.32	220.93	7.46
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.51	22.86	125.43	2.48
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	4.10	17.87	35.84	3.14
	Total Diesel	10.15	42.79	164.41	5.92
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.20	10.71	57.10	1.32
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	3.19	12.11	25.53	2.16
	Total Diesel	7.81	24.73	85.62	3.71
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.64	5.98	27.90	0.88
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.62	7.48	17.21	1.26
	Total Diesel	6.59	15.00	47.97	2.31

Table B-11. On- and Off-Highway California Diesel Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.2%	0.0%	6.0%	7.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	1.1%
	Heavy-Duty Off-Highway	30.0%	0.0%	8.6%	12.3%
	Total Diesel	20.3%	0.0%	6.3%	8.9%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	12.6%	0.0%	5.1%	6.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	27.2%	0.0%	8.6%	10.2%
	Total Diesel	17.3%	0.0%	5.7%	8.1%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.3%	0.0%	4.5%	4.8%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	27.2%	0.0%	8.6%	10.2%
	Total Diesel	13.5%	0.0%	5.5%	7.6%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	2.9%	0.0%	3.5%	2.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	27.2%	0.0%	8.6%	10.2%
	Total Diesel	11.2%	0.0%	5.1%	6.3%

Table B-12. On- and Off-Highway California Diesel Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	17.2%	17.2%	17.2%	17.2%	17.2%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	30.0%	30.0%	30.0%	30.0%	30.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	12.6%	12.6%	12.6%	12.6%	12.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	27.2%	27.2%	27.2%	27.2%	27.2%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.3%	6.3%	6.3%	6.3%	6.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	27.2%	27.2%	27.2%	27.2%	27.2%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	2.9%	2.9%	2.9%	2.9%	2.9%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	27.2%	27.2%	27.2%	27.2%	27.2%

Table B-13. On-Highway 5% Biodiesel Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.12	34.96	166.55	3.51
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	3.70	18.36	36.57	3.01
	Total Diesel	10.72	56.40	206.94	6.95
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.16	23.59	118.80	2.39
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.23	17.87	33.00	2.85
	Total Diesel	8.92	43.53	154.94	5.55
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.16	11.05	54.36	1.30
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.51	12.11	23.50	1.96
	Total Diesel	7.09	25.07	80.86	3.49
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.72	6.17	26.81	0.89
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.06	7.48	15.85	1.14
	Total Diesel	6.12	15.19	45.52	2.20

Table B-14. On-Highway 5% Biodiesel Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	5.4%	3.2%	-0.5%	3.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	3.0%	2.0%	-0.4%	1.5%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	5.4%	3.2%	-0.5%	3.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	3.1%	1.7%	-0.4%	1.3%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	5.4%	3.2%	-0.5%	3.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	3.1%	1.4%	-0.3%	1.1%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	5.4%	3.2%	-0.5%	3.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	3.2%	1.3%	-0.3%	1.2%

Table B-15. On-Highway 5% Biodiesel Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.8%	0.8%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.8%	0.8%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.8%	0.8%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.8%	0.8%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%

Table B-16. On-Highway 20% Biodiesel Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.97	38.04	164.04	3.81
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	3.70	18.36	36.57	3.01
	Total Diesel	11.57	59.49	204.43	7.25
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.88	25.67	117.01	2.60
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.23	17.87	33.00	2.85
	Total Diesel	9.64	45.61	153.15	5.76
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.74	12.03	53.54	1.41
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.51	12.11	23.50	1.96
	Total Diesel	7.67	26.05	80.04	3.60
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	4.24	6.71	26.41	0.96
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.06	7.48	15.85	1.14
	Total Diesel	6.64	15.74	45.11	2.27

Table B-17. On-Highway 20% Biodiesel Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	20.1%	12.3%	-2.0%	12.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	11.2%	7.5%	-1.6%	6.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	20.1%	12.3%	-2.0%	12.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	11.4%	6.6%	-1.5%	5.1%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	20.1%	12.3%	-2.0%	12.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	11.5%	5.3%	-1.3%	4.4%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	20.1%	12.3%	-2.0%	12.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	12.0%	4.9%	-1.2%	4.8%

Table B-18. On-Highway 20% Biodiesel Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.2%	3.4%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.2%	3.4%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.2%	3.4%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	3.2%	3.4%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%

Table B-19. On-Highway Level 1 Diesel Retrofit Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	6.87	39.20	167.38	3.90
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	3.70	18.36	36.57	3.01
	Total Diesel	11.47	60.64	207.78	7.34
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.57	26.26	119.39	2.64
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.23	17.87	33.00	2.85
	Total Diesel	9.33	46.20	155.54	5.80
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.31	12.53	54.64	1.50
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.51	12.11	23.50	1.96
	Total Diesel	7.24	26.54	81.14	3.69
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.68	6.66	26.95	0.94
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.06	7.48	15.85	1.14
	Total Diesel	6.08	15.68	45.65	2.25

Table B-20. On-Highway Level 1 Diesel Retrofit Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	18.3%	15.7%	0.0%	14.4%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	10.2%	9.6%	0.0%	7.2%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.8%	14.9%	0.0%	13.7%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	7.8%	7.9%	0.0%	5.8%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	9.2%	16.9%	0.0%	18.9%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	5.3%	7.3%	0.0%	6.9%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	4.2%	11.4%	0.0%	9.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	2.5%	4.5%	0.0%	3.6%

Table B-21. On-Highway Level 1 Diesel Retrofit Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	18.3%	18.3%	18.3%	18.3%	18.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.8%	13.8%	13.8%	13.8%	13.8%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	9.2%	9.2%	9.2%	9.2%	9.2%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	4.2%	4.2%	4.2%	4.2%	4.2%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%

Table B-22. On-Highway Level 2 Diesel Retrofit Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	7.20	40.65	167.38	3.93
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	3.70	18.36	36.57	3.01
	Total Diesel	11.80	62.09	207.78	7.37
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	5.78	27.20	119.39	2.66
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.23	17.87	33.00	2.85
	Total Diesel	9.55	47.14	155.54	5.82
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.37	12.70	54.64	1.44
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.51	12.11	23.50	1.96
	Total Diesel	7.30	26.72	81.14	3.63
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.76	7.00	26.95	0.98
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.06	7.48	15.85	1.14
	Total Diesel	6.15	16.02	45.65	2.29

Table B-23. On-Highway Level 2 Diesel Retrofit Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	24.0%	20.0%	0.0%	15.5%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	13.4%	12.2%	0.0%	7.7%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	18.1%	19.0%	0.0%	14.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	10.2%	10.2%	0.0%	6.2%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	10.6%	18.6%	0.0%	14.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	6.1%	8.1%	0.0%	5.2%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.4%	17.0%	0.0%	13.7%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	3.8%	6.8%	0.0%	5.4%

Table B-24. On-Highway Level 2 Diesel Retrofit Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	24.0%	24.0%	24.0%	24.0%	24.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	18.1%	18.1%	18.1%	18.1%	18.1%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	10.6%	10.6%	10.6%	10.6%	10.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	6.4%	6.4%	6.4%	6.4%	6.4%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%

Table B-25. On-Highway Level 3 Diesel Retrofit Program Criteria Pollutant Inventory (Tons/Day)

Calendar Year	Diesel Class	Exhaust Inventory			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.58	1.29	1.54	0.17
	Heavy-Duty On-Highway	7.84	43.59	262.65	5.17
	Light-Duty Off-Highway	0.73	2.54	2.89	0.43
	Heavy-Duty Off-Highway	4.32	20.68	39.84	3.94
	Total Diesel	13.47	68.11	306.92	9.71
2007	Light-Duty On-Highway	0.35	0.94	0.93	0.08
	Heavy-Duty On-Highway	7.55	42.34	167.38	4.15
	Light-Duty Off-Highway	0.54	2.15	2.89	0.35
	Heavy-Duty Off-Highway	3.70	18.36	36.57	3.01
	Total Diesel	12.14	63.79	207.78	7.59
2010	Light-Duty On-Highway	0.10	0.20	0.21	0.02
	Heavy-Duty On-Highway	6.01	28.29	119.39	2.80
	Light-Duty Off-Highway	0.44	1.87	2.94	0.29
	Heavy-Duty Off-Highway	3.23	17.87	33.00	2.85
	Total Diesel	9.77	48.23	155.54	5.96
2015	Light-Duty On-Highway	0.12	0.55	0.20	0.02
	Heavy-Duty On-Highway	4.47	13.20	54.64	1.52
	Light-Duty Off-Highway	0.31	1.36	2.79	0.21
	Heavy-Duty Off-Highway	2.51	12.11	23.50	1.96
	Total Diesel	7.40	27.22	81.14	3.70
2020	Light-Duty On-Highway	0.08	0.50	0.12	0.02
	Heavy-Duty On-Highway	3.82	7.25	26.95	1.03
	Light-Duty Off-Highway	0.25	1.05	2.74	0.15
	Heavy-Duty Off-Highway	2.06	7.48	15.85	1.14
	Total Diesel	6.21	16.27	45.65	2.34

Table B-26. On-Highway Level 3 Diesel Retrofit Program Criteria Pollutant Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction			
		VOC	CO	NOx	PM2.5
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	30.0%	25.0%	0.0%	21.9%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	16.7%	15.3%	0.0%	10.9%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	22.7%	23.8%	0.0%	20.6%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	12.8%	12.7%	0.0%	8.7%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.2%	23.3%	0.0%	20.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	7.6%	10.1%	0.0%	7.3%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	8.0%	21.3%	0.0%	19.3%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%
	Total Diesel	4.7%	8.5%	0.0%	7.7%

Table B-27. On-Highway Level 3 Diesel Retrofit Program Toxic Species Inventory (Percent Reduction)

Calendar Year	Diesel Class	Exhaust Inventory Reduction				
		Acetaldehyde	Formaldehyde	Acrolein	1,3-Butadiene	Benzene
2002	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2007	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	30.0%	30.0%	30.0%	30.0%	30.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2010	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	22.7%	22.7%	22.7%	22.7%	22.7%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2015	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	13.2%	13.2%	13.2%	13.2%	13.2%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
2020	Light-Duty On-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty On-Highway	8.0%	8.0%	8.0%	8.0%	8.0%
	Light-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%
	Heavy-Duty Off-Highway	0.0%	0.0%	0.0%	0.0%	0.0%

Attachment C - Per-Vehicle Diesel Retrofit Results

This attachment provides additional diesel retrofit modeling results reported on a per-vehicle basis. These data are provided to facilitate the analysis of a retrofit program that targets a specific fleet (of known vehicle classes with known operating characteristics). Results are reported separately by the nine heavy-duty diesel vehicle classes of MOBILE6.2. Also reported is the average miles traveled per day, which is a MOBILE6.2 fleet composite. If daily miles of travel are known for the retrofit fleet, these results should be scaled accordingly.

Results are a function of calendar year. Tables C-1 through C-4 present the results for 2007, 2010, 2015 and 2020, respectively.

Table C-1. 2007 Retrofit Benefits on a Per-Vehicle Basis by Diesel Vehicle Class

Retrofit Level	Vehicle Class	MOBILE6.2 Average Miles per Day	VOC Benefit (g/Day)	CO Benefit (g/Day)	NOx Benefit (g/Day)	PM2.5 Benefit (g/Day)
1	Diesel School Bus	27.2	2.92	8.26	0.00	1.60
1	Diesel Commercial Bus	91.6	5.60	49.83	0.00	4.53
1	Heavy-Duty Diesel Vehicle 8B	145.5	14.03	64.93	0.00	4.73
1	Heavy-Duty Diesel Vehicle 8A	89.7	7.41	33.85	0.00	2.88
1	Heavy-Duty Diesel Vehicle 7	47.9	4.26	13.14	0.00	1.36
1	Heavy-Duty Diesel Vehicle 6	48.2	3.51	10.70	0.00	1.38
1	Heavy-Duty Diesel Vehicle 5	47.8	2.53	9.12	0.00	0.67
1	Heavy-Duty Diesel Vehicle 4	47.2	2.25	8.19	0.00	0.68
1	Heavy-Duty Diesel Vehicle 3	32.0	1.27	4.84	0.00	0.45
1	Heavy-Duty Diesel Vehicle 2B	33.9	1.22	4.31	0.00	0.52
2	Diesel School Bus	27.2	2.81	7.69	0.00	0.60
2	Diesel Commercial Bus	94.5	4.34	52.55	0.00	2.09
2	Heavy-Duty Diesel Vehicle 8B	159.3	19.96	84.97	0.00	4.62
2	Heavy-Duty Diesel Vehicle 8A	99.3	10.61	44.99	0.00	2.90
2	Heavy-Duty Diesel Vehicle 7	52.3	5.91	17.40	0.00	1.34
2	Heavy-Duty Diesel Vehicle 6	52.5	4.85	14.12	0.00	1.37
2	Heavy-Duty Diesel Vehicle 5	50.4	3.22	12.95	0.00	0.64
2	Heavy-Duty Diesel Vehicle 4	50.2	2.85	11.87	0.00	0.64
2	Heavy-Duty Diesel Vehicle 3	35.6	1.74	7.23	0.00	0.47
2	Heavy-Duty Diesel Vehicle 2B	37.4	1.60	6.56	0.00	0.50
3	Diesel School Bus	27.2	4.61	12.24	0.00	0.92
3	Diesel Commercial Bus	94.5	5.42	65.69	0.00	2.96
3	Heavy-Duty Diesel Vehicle 8B	159.3	24.95	106.22	0.00	6.54
3	Heavy-Duty Diesel Vehicle 8A	99.3	13.26	56.24	0.00	4.11
3	Heavy-Duty Diesel Vehicle 7	52.3	7.39	21.75	0.00	1.90
3	Heavy-Duty Diesel Vehicle 6	52.5	6.06	17.65	0.00	1.94
3	Heavy-Duty Diesel Vehicle 5	50.4	4.03	16.19	0.00	0.90
3	Heavy-Duty Diesel Vehicle 4	50.2	3.57	14.84	0.00	0.90
3	Heavy-Duty Diesel Vehicle 3	35.6	2.17	9.03	0.00	0.66
3	Heavy-Duty Diesel Vehicle 2B	37.4	1.99	8.20	0.00	0.71

Table C-2. 2010 Retrofit Benefits on a Per-Vehicle Basis by Diesel Vehicle Class

Retrofit Level	Vehicle Class	MOBILE6.2 Average Miles per Day	VOC Benefit (g/Day)	CO Benefit (g/Day)	NOx Benefit (g/Day)	PM2.5 Benefit (g/Day)
1	Diesel School Bus	27.2	2.23	8.07	0.00	1.59
1	Diesel Commercial Bus	85.9	2.85	38.55	0.00	2.50
1	Heavy-Duty Diesel Vehicle 8B	108.4	8.30	47.89	0.00	3.48
1	Heavy-Duty Diesel Vehicle 8A	63.4	4.11	23.42	0.00	2.02
1	Heavy-Duty Diesel Vehicle 7	35.6	2.43	9.69	0.00	1.02
1	Heavy-Duty Diesel Vehicle 6	35.9	2.01	7.89	0.00	1.03
1	Heavy-Duty Diesel Vehicle 5	39.3	1.61	7.22	0.00	0.54
1	Heavy-Duty Diesel Vehicle 4	38.8	1.41	6.48	0.00	0.56
1	Heavy-Duty Diesel Vehicle 3	22.2	0.67	3.22	0.00	0.31
1	Heavy-Duty Diesel Vehicle 2B	26.0	0.71	3.17	0.00	0.40
2	Diesel School Bus	27.2	2.15	7.53	0.00	0.60
2	Diesel Commercial Bus	86.9	3.03	46.19	0.00	1.81
2	Heavy-Duty Diesel Vehicle 8B	118.7	11.92	63.32	0.00	3.37
2	Heavy-Duty Diesel Vehicle 8A	70.3	5.93	31.38	0.00	2.01
2	Heavy-Duty Diesel Vehicle 7	38.9	3.39	12.94	0.00	0.99
2	Heavy-Duty Diesel Vehicle 6	39.1	2.79	10.51	0.00	1.01
2	Heavy-Duty Diesel Vehicle 5	41.4	2.06	10.30	0.00	0.51
2	Heavy-Duty Diesel Vehicle 4	41.2	1.80	9.42	0.00	0.51
2	Heavy-Duty Diesel Vehicle 3	24.7	0.92	4.83	0.00	0.32
2	Heavy-Duty Diesel Vehicle 2B	28.7	0.94	4.84	0.00	0.37
3	Diesel School Bus	27.2	3.53	12.03	0.00	0.90
3	Diesel Commercial Bus	86.9	3.79	57.74	0.00	2.56
3	Heavy-Duty Diesel Vehicle 8B	118.7	14.90	79.15	0.00	4.78
3	Heavy-Duty Diesel Vehicle 8A	70.3	7.41	39.22	0.00	2.85
3	Heavy-Duty Diesel Vehicle 7	38.9	4.24	16.18	0.00	1.40
3	Heavy-Duty Diesel Vehicle 6	39.1	3.49	13.13	0.00	1.43
3	Heavy-Duty Diesel Vehicle 5	41.4	2.57	12.87	0.00	0.72
3	Heavy-Duty Diesel Vehicle 4	41.2	2.25	11.78	0.00	0.73
3	Heavy-Duty Diesel Vehicle 3	24.7	1.16	6.04	0.00	0.45
3	Heavy-Duty Diesel Vehicle 2B	28.7	1.18	6.05	0.00	0.53

Table C-3. 2015 Retrofit Benefits on a Per-Vehicle Basis by Diesel Vehicle Class

Retrofit Level	Vehicle Class	MOBILE6.2 Average Miles per Day	VOC Benefit (g/Day)	CO Benefit (g/Day)	NOx Benefit (g/Day)	PM2.5 Benefit (g/Day)
1	Diesel School Bus	27.2	1.59	10.12	0.00	4.45
1	Diesel Commercial Bus	75.9	1.90	39.79	0.00	4.19
1	Heavy-Duty Diesel Vehicle 8B	60.2	3.32	33.39	0.00	3.76
1	Heavy-Duty Diesel Vehicle 8A	32.0	1.48	14.56	0.00	1.95
1	Heavy-Duty Diesel Vehicle 7	19.8	0.96	6.68	0.00	1.11
1	Heavy-Duty Diesel Vehicle 6	20.0	0.80	5.46	0.00	1.12
1	Heavy-Duty Diesel Vehicle 5	27.0	0.82	5.51	0.00	0.71
1	Heavy-Duty Diesel Vehicle 4	26.3	0.71	4.79	0.00	0.73
1	Heavy-Duty Diesel Vehicle 3	10.9	0.24	1.73	0.00	0.28
1	Heavy-Duty Diesel Vehicle 2B	15.2	0.31	2.01	0.00	0.45
2	Diesel School Bus	27.2	1.50	9.02	0.00	1.00
2	Diesel Commercial Bus	77.4	1.62	40.43	0.00	1.80
2	Heavy-Duty Diesel Vehicle 8B	72.6	4.62	40.00	0.00	2.43
2	Heavy-Duty Diesel Vehicle 8A	39.5	2.08	17.88	0.00	1.33
2	Heavy-Duty Diesel Vehicle 7	23.8	1.26	8.16	0.00	0.72
2	Heavy-Duty Diesel Vehicle 6	23.9	1.04	6.63	0.00	0.74
2	Heavy-Duty Diesel Vehicle 5	29.8	0.91	7.41	0.00	0.43
2	Heavy-Duty Diesel Vehicle 4	29.7	0.79	6.76	0.00	0.43
2	Heavy-Duty Diesel Vehicle 3	13.4	0.30	2.60	0.00	0.20
2	Heavy-Duty Diesel Vehicle 2B	18.4	0.37	3.08	0.00	0.28
3	Diesel School Bus	27.2	2.15	12.37	0.00	1.06
3	Diesel Commercial Bus	77.4	2.02	50.54	0.00	2.56
3	Heavy-Duty Diesel Vehicle 8B	72.6	5.78	50.00	0.00	3.44
3	Heavy-Duty Diesel Vehicle 8A	39.5	2.59	22.35	0.00	1.88
3	Heavy-Duty Diesel Vehicle 7	23.8	1.57	10.20	0.00	1.02
3	Heavy-Duty Diesel Vehicle 6	23.9	1.30	8.28	0.00	1.04
3	Heavy-Duty Diesel Vehicle 5	29.8	1.14	9.26	0.00	0.61
3	Heavy-Duty Diesel Vehicle 4	29.7	0.99	8.45	0.00	0.62
3	Heavy-Duty Diesel Vehicle 3	13.4	0.38	3.25	0.00	0.29
3	Heavy-Duty Diesel Vehicle 2B	18.4	0.46	3.85	0.00	0.40

Table C-4. 2020 Retrofit Benefits on a Per-Vehicle Basis by Diesel Vehicle Class

Retrofit Level	Vehicle Class	MOBILE6.2 Average Miles per Day	VOC Benefit (g/Day)	CO Benefit (g/Day)	NOx Benefit (g/Day)	PM2.5 Benefit (g/Day)
1	Diesel School Bus	27.2	0.69	5.97	0.00	0.54
1	Diesel Commercial Bus	64.1	0.53	19.21	0.00	1.15
1	Heavy-Duty Diesel Vehicle 8B	43.2	1.13	14.05	0.00	1.14
1	Heavy-Duty Diesel Vehicle 8A	21.4	0.46	5.66	0.00	0.57
1	Heavy-Duty Diesel Vehicle 7	14.1	0.30	2.86	0.00	0.37
1	Heavy-Duty Diesel Vehicle 6	14.1	0.25	2.31	0.00	0.38
1	Heavy-Duty Diesel Vehicle 5	21.0	0.26	3.02	0.00	0.24
1	Heavy-Duty Diesel Vehicle 4	21.0	0.22	2.77	0.00	0.24
1	Heavy-Duty Diesel Vehicle 3	7.1	0.06	0.79	0.00	0.08
1	Heavy-Duty Diesel Vehicle 2B	11.7	0.09	1.13	0.00	0.14
2	Diesel School Bus	27.2	0.69	5.97	0.00	0.54
2	Diesel Commercial Bus	64.1	0.80	28.81	0.00	1.72
2	Heavy-Duty Diesel Vehicle 8B	43.2	1.69	21.07	0.00	1.71
2	Heavy-Duty Diesel Vehicle 8A	21.4	0.68	8.49	0.00	0.85
2	Heavy-Duty Diesel Vehicle 7	14.1	0.45	4.28	0.00	0.55
2	Heavy-Duty Diesel Vehicle 6	14.1	0.37	3.47	0.00	0.56
2	Heavy-Duty Diesel Vehicle 5	21.0	0.39	4.53	0.00	0.36
2	Heavy-Duty Diesel Vehicle 4	21.0	0.34	4.15	0.00	0.36
2	Heavy-Duty Diesel Vehicle 3	7.1	0.10	1.19	0.00	0.13
2	Heavy-Duty Diesel Vehicle 2B	11.7	0.14	1.69	0.00	0.21
3	Diesel School Bus	27.2	1.30	11.20	0.00	1.14
3	Diesel Commercial Bus	64.1	1.00	36.01	0.00	2.44
3	Heavy-Duty Diesel Vehicle 8B	43.2	2.11	26.34	0.00	2.42
3	Heavy-Duty Diesel Vehicle 8A	21.4	0.86	10.61	0.00	1.21
3	Heavy-Duty Diesel Vehicle 7	14.1	0.56	5.35	0.00	0.78
3	Heavy-Duty Diesel Vehicle 6	14.1	0.46	4.34	0.00	0.80
3	Heavy-Duty Diesel Vehicle 5	21.0	0.49	5.66	0.00	0.51
3	Heavy-Duty Diesel Vehicle 4	21.0	0.42	5.19	0.00	0.52
3	Heavy-Duty Diesel Vehicle 3	7.1	0.12	1.49	0.00	0.18
3	Heavy-Duty Diesel Vehicle 2B	11.7	0.17	2.12	0.00	0.30