Effects of E15 Ethanol Blends on HC, CO, and NOx Regulated Emissions from On-Road 2001 and Later Model Year Motor Vehicles

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For Renewable Fuels Association

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1.0 Summary

On October 13, 2010, and again on January 11, 2011, EPA approved a waiver for a 15% blend of ethanol and gasoline (E15) for 2001 and later on-road cars and light duty trucks. Prior to the approval of these waivers, ethanol in gasoline was limited to 10% by volume (E10). In their evaluation of testing data used to support these decisions, EPA determined that an E15 blend would not result in 2001 and newer on-road vehicles failing their full-life emission standards. However, EPA did not determine the short-term directional impact that E15 would have on HC, CO, and NOx emissions from these vehicles, relative to an E10 blend, since this was not a focus of the waiver determination. The E15 waiver did not extend to 2000 and earlier vehicles, or to off-road vehicles or engines.

This study examined the available exhaust and evaporative emissions data on intermediate blends (i.e., those between E10 and E20), to determine the impact E15 would have on overall air quality once approved for 2001 and later vehicles, relative to E10. Three exhaust emission studies on 2001 and later model year vehicles were examined, and two evaporative emission studies were examined. For exhaust emissions, generally, exhaust HC and CO emissions appear to be lower with E15 than E10, and NOx either about the same or slightly higher. However, the data in the E10 to E15 range is still quite sketchy.

There are three main sources of evaporative emissions from vehicles, and the ethanol effects for two out of three sources can be different. These three sources are permeation, leaks, and gasoline + ethanol vapor. For evaporative permeation emissions, we could discern no trend in emissions between E10 and E15. There are no differences in leak emissions between E10 and E15. For evaporative vapor emissions, EPA's approval of the E15 waiver does not allow E15 to receive a 1 psi volatility wavier like E10 does. Both vapor evaporative and exhaust VOC emissions are generally lower with lower volatility fuel. Therefore, areas of the U.S. with a 1 psi waiver for ethanol would experience a reduction in vapor emissions from 2001 and later model year vehicles, to the extent that these vehicles switch form E10 to E15. This study examined the effects in calendar year 2020 of the state of Minnesota switching from E10 to E15 for 2001 and later vehicles (this state has a 1 psi volatility waiver for E10). Total on-road gasoline vehicle VOC emissions in the state would be reduced by about 3% in 2020 with E15 as compared to E10. The percent reductions in 2011 would be somewhat less, around 1.5% or so.

Overall, this study indicates that E15 would reduce VOC evaporative and exhaust emissions, reduce CO and either have no effect on NOx or a slight increase. We recommend additional exhaust emissions testing on E10, E15, and E20.

2.0 Introduction

EPA's Renewable Fuel Standard, promulgated in 2010 predicted that ethanol blending in the U.S. would hit a "blend wall" – that is – the volume of ethanol at which nearly every vehicle in the U.S. is operated on E10 – in or around 2012. [1] Expanding ethanol beyond this blend wall volume would either require (1) a massive increase in E85 and/or blender pumps that dispense varying mixtures of ethanol and gasoline into FFVs, or (2) an increase in the allowable ethanol volume that can legally be blended in gasoline and used for motor vehicles or other sources utilizing gasoline, or both.

In late 2010 and early 2011, EPA approved a waiver for E15 – a blend of up to 15 volume percent ethanol in gasoline – in 2001 and later on-road light duty cars and light duty trucks. EPA's decision was based on extensive testing data that showed that E15 did not cause these vehicles to exceed their emission standards over their useful life. However, EPA did not specifically examine the directional impact that E15 has on HC, CO, and NOx emissions from these vehicles relative to E10. This is an important factor for states to be aware of in reducing emissions to meet local air quality goals such as the ozone standards.

Since the E15 waiver was approved only for 2001 and later passenger cars and light duty trucks, this study estimates the impacts of E15 relative to E10 on HC, CO, and NOx emissions from these particular vehicles only. The analysis evaluates evaporative emissions as well as exhaust emissions, and examines a number of recent testing programs conducted on ethanol blends above and below the E10 level. The possible effects on particulate matter are not discussed because no test data are available on PM emissions from motor vehicles at ethanol levels above E10.

This study does not address the effect of ethanol on greenhouse (GHG) emissions. The effect of ethanol on GHG emissions is usually discussed in the "lifecycle" context – where lifecycle consists not only of the emissions when the fuel is burned in the engine, but all of the GHG emissions associated with bringing both gasoline and ethanol to the vehicle. For gasoline, these are the emissions associated with finding, pumping, and transporting crude oil to the refinery, as well as producing gasoline and shipping gasoline to the service station. For ethanol, these are the emissions associated with farming the feedstock (usually corn in the U.S.), shipping the feedstock to an ethanol plant, processing the feedstock into ethanol, and transporting the ethanol to the ethanol blending facility. For ethanol, this may also include indirect land use changes. In its 2010 Renewable Fuel Standard Rule, EPA concluded that corn ethanol made in a typical U.S. natural gas dry mill plant reduced GHG emissions by about 19% from gasoline. [1][1]

The report is divided into the following sections:

- Background

[1] See Table V.C-1 in this reference.

- Exhaust Emissions
- Evaporative Emissions
- Overall Impacts of E15 on Emissions from 2001 and Later Vehicles

3.0 Background

The Energy Independence and Security Act of 2007 calls on the nation to significantly expand its use of renewable fuels to meet its transportation needs. The law expands the renewable fuel standard (RFS) to require the use of 36 billion gallons of renewable fuel by 2022. Given that ethanol is the most widely used renewable fuel in the U.S. market, ethanol will likely make up a significant portion of the 36-billion gallon requirement.

The vast majority of ethanol used in the U.S. is blended with gasoline to create E10 – gasoline with up to 10% ethanol. The remaining ethanol is sold in the form of E85 – a gasoline blend with as much as 85% ethanol that can be used only in flexible-fueled vehicles (FFVs). Consumption of E85 is currently limited by both the size of the flex-fueled fleet and the number of either E85 fueling stations, or stations with blender pumps.[2]

Given the projected growth in ethanol production and the new RFS, the E10 market is expected to be saturated by 2012. The volume at which E10 is saturated is referred to as the "blend wall."

3.1 E15 Waiver

In March 2009, Growth Energy and 54 ethanol manufacturers petitioned the EPA to allow the introduction into commerce of up to 15 volume percent ethanol in gasoline, Prior to Growth Energy's petition ethanol was limited to 10 volume percent. On October 13, 2010, EPA took two actions on the wavier request based on the information available at that time. First, it approved Growth Energy's wavier request to allow the introduction of E15 into commerce for use in model year 2007 and newer light duty motor vehicles, subject to several conditions. [2] Second, the waiver request denied the petition for 2000 and earlier vehicles, heavy-duty gasoline vehicles, highway and off-highway motorcycles, and other non-road engines, vehicles, and equipment. On January 26, 2011, the E15 waiver was further granted for 2001-2006 vehicles, so that the E15 waiver is for all 2001 and later light duty vehicles and light duty trucks. [3] All other conditions of the October 13 waiver remained in effect.

To receive a waiver under the Clean Air Act Amendments (CAA), a fuel or fuel additive manufacturer must demonstrate that a new fuel or fuel additive will not cause or contribute to the failure of engines or vehicles to achieve compliance with the emission standard to which they have been certified over their useful life. According to the EPA, the information submitted by Growth Energy was not sufficient for EPA to make this determination. However, information submitted later, in particular an extensive Catalyst

[2] In January of 2011, the RFA released a report by AIR that showed that the domestic manufacturers' commitment to ramp up FFV production to the 50% of the fleet goes a long way to ensuring that there could be enough FFVs on the road to utilize much of the ethanol, however, the lack of implementation of blender pumps is a more serious impediment. [4]

Testing Program conducted by the Department of Energy, formed the basis of the EPA E15 waiver decision. That is, based primarily on the DOE Catalyst Testing program but also other information, EPA concluded that E15 would not cause 2001 and later vehicles to exceed their emission standards. However, the EPA waiver decision did not specifically determine the directional impact that E15 has on HC, CO, and NOx emissions relative to E10. This information is relevant, however, to states trying to reduce emissions to attain air quality standards such as the ozone standard.

The manner in which ethanol is blended with gasoline can also have an effect on vehicle emissions. There are generally two types of blending techniques – splash blending, and match blending. In splash blending, ethanol is added to a conventional gasoline, without too much consideration for the final properties of the gasoline/ethanol mix. In match blending, the base gasoline properties are altered so that the final gasoline/ethanol mix has a set of targeted properties. For example, ethanol has a higher octane level than gasoline. In splash blending, ethanol is added to a gasoline with a minimum 87 (R+M)/2 and the final mix will have an octane value above 87. In match blending, the octane level of the base gasoline does not meet the minimum requirement until the ethanol is added, so that the final octane level of the mix is 87.

There is a combination of match blending and splash blending in the U.S. today. Most if not all areas with reformulated gasoline containing ethanol utilize match blending. Areas outside may be either splash blended or match blended, with the method selected depending on local requirements (for fuel volatility, for example) and cost.

The E15 waiver for 2001 and newer model year vehicles denies the RVP waiver for ethanol-blended gasoline, so EPA expects all E15 to be supplied as match-blends. In states with a 1 psi ethanol waiver, then, the use of E15 in 2001 and later vehicles will result in lower evaporative emissions from 2001 and later vehicles due to E15 having a lower RVP than E10.

As stated earlier, the type of blending does affect emissions. For example, the benzene content of gasoline is limited to 0.6 weight % by EPA Toxics Rules. Ethanol has no benzene. If ethanol is match-blended, it could be blended with a base gasoline with a slightly higher benzene content than 0.6%, so the finished blend is at or less than 0.6 weight percent. But if it is splash blended with a 0.6 weight percent gasoline, the finished gasoline will have a benzene content of less than 0.6%, and benzene emissions for the splash blended gasoline will be less than the match-blended gasoline.

This study's review of the available test data shows that both match- and splash-blended mixtures were used in various test programs. This study will point out those differences when the information is available.

3.2 Effect of Ethanol Blends Less Than 10% on Criteria Pollutant Emissions

It is instructive to review the effects of ethanol on emissions for blends at 10% or less, because the trends in emissions that exist between E0 and E10 probably continue above

E10, at least for exhaust emissions. [3] Many studies have been conducted on 10% and lower ethanol blends, and a review of all of these studies is beyond the scope of this paper. However, the CRC E-84 study summarized the effects of many different fuel parameters on criteria pollutant emissions, drawing on many different test programs. [5] The study concluded

> In studies where composition and volatility were controlled, adding oxygenates to gasoline resulted in lower HC and CO emissions, even in cars with sophisticated engineered control systems. Emissions of NOx tended to increase, although this effect was not measured in all programs. There was generally no difference between different kinds of oxygenates – alcohols and ethers. The most recent data suggest that the CO effect is still relevant, but the HC effect might be smaller or even non-existent in the newest technology. While overall toxic emissions may be lower when oxygenates are added to gasoline, oxygenates usually increase emissions of aldehydes…...

3.3 Studies of Malfunction Indicator Light Illumination

The Coordinating Research Council has conducted two studies to determine whether E10+ blends would result in malfunction indicator light (MIL) illumination in vehicles operated on E10+ blends. All 1996 and later cars and light duty trucks are equipped with onboard diagnostic (OBD) systems. These studies are briefly summarized below.

3.2.1 CRC E-90 Study

CRC conducted a pilot study to determine the impact of E15/E20 blends on onboard diagnostic systems. [6] The authors of the study identified inspection and maintenance programs that were operated in areas where gasoline with no ethanol and 10% ethanol was dispensed. They set up a test program where long-term fuel trim (LTFT) and other parameters were recorded over a 10-minute period after vehicles received their periodic I/M test. The primary finding of this study was:

> The tests conducted in this study provide evidence that operation on 15% or 20% ethanol/gasoline blends may cause a subset of problem-free vehicles to illuminate their malfunction indicator light (MIL) due to excessively lean operation. The fraction depends on the assumed LTFT threshold and the fuel ethanol content and is roughly estimated to be of the order of 1 percent or so.

[3] A small amount of ethanol increases fuel volatility by about 1 psi, thereby leading to an increase in evaporative emissions, with the size of the increase depending on the vehicle technology. However, as ethanol content increases above about 3-4%, fuel volatility starts to decline, therefore, the trends for evaporative emissions above E10 would not reflect the trends between E0 and E10.

This study did not examine whether emissions change at blends above E10, only whether the MIL would illuminate, and the study concludes that this is possible, but only in about 1 % of the vehicles.

3.2.2 CRC E90-2a

CRC conducted a related study to further examine inspection and maintenance data to identify vehicles that may be sensitive to E10+ blends. I/M data were examined from Atlanta, Southern California, Denver, and Vancouver. [7]

> The analysis reveals that the onboard diagnostic systems in certain model light-duty vehicles are detecting significantly more fuel metering-related faults when operating on gasoline blended with 10% ethanol by volume than when operating with gasoline with lower ethanol content…..based on the analysis performed, approximately 4% of all OBD-equipped light duty vehicles could be susceptible to fuel metering-related fault codes when using E10+

Again, this study did not examine whether emissions change above E10, only whether the MIL would illuminate, and the study concludes that it could or may occur in about 4 percent of OBD-equipped vehicles.

4.0 Exhaust Emissions

The exhaust emission effects of ethanol at ethanol concentrations between 0 and 10 volume percent have been studied extensively in the past 30 years. There are several things that are well known about the emission effects of ethanol in this range of concentrations:

- Increasing ethanol content generally reduces both VOC and CO, especially for "higher emitting" vehicles
- Increasing ethanol content either has no effect on NOx, or it can increase NOx in some newer technology vehicles.
- The size of the above impacts depends on the vehicle technology being evaluated

Since the E15 waiver has been approved by the EPA for 2001 and later vehicles, and most of the nation is moving quickly to E10 because of the Renewable Fuel Standard, the focus of this study is on the emission impacts of E15 relative to E10 for 2001 and later vehicles.

There are several studies or sources of data that can be used to determine the impacts of E15 fuel relative to E10:

- CRC E-74b emissions study
- DOE Study of Intermediate Blends on Legacy Vehicles
- DOE Catalyst Study

These studies are examined further below.

4.1 CRC E-74b Study

The Coordinating Research Council (CRC) E-74b study examined the effects of vapor pressure, oxygen and temperature on CO exhaust emissions, but NMHC and NOx were also examined in this study. [8] Eleven 2001 and later vehicles were tested on 7 different fuels, with vapor pressures ranging from 6.95 to 13.3 psi, and ethanol contents of 0, 10 (9.5), and 20 (20.4). [4] The standard Federal Test Procedure (FTP) driving cycle was used. No testing was performed on an E15 fuel. The test vehicle and fuel specification lists are shown in Attachment 1.

The test fuels were specifically prepared for this program. The RVP of the finished fuels were targeted at levels of 7, 9, and 13 psi. Ethanol contents of E0, E10, and E20 were specified. The base stocks for the E10 and E20 fuels were intended to yield appropriate RVP and other properties following the addition of ethanol (i.e., they were essentially match-blended). For example, examination of sulfur and octane levels of the E10 and E20 fuels showed that the levels were very similar.

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[4] Four 1999 and earlier vehicles were also tested, but these will not be discussed in this paper, because the E15 waiver does not apply to these vehicles.

The researchers in the E-74b study performed a statistical analysis of all of the data (2001 and later and pre-2001), and concluded that emissions versus oxygen content (holding RVP constant) looks like Figure 1 (which is Figure ES-2 from the report). Figure 2 shows the same data normalized to E10. With increasing ethanol content, total hydrocarbon and CO decline, but NOx increases. Between E10 and E15, THC is reduced by 4%, CO by 6%, and NOx increases by 4% (all relative to the emissions at E10). However, these curves are based on all of the data, where our study is examining only data on 2001 and later vehicles.

Figure 1

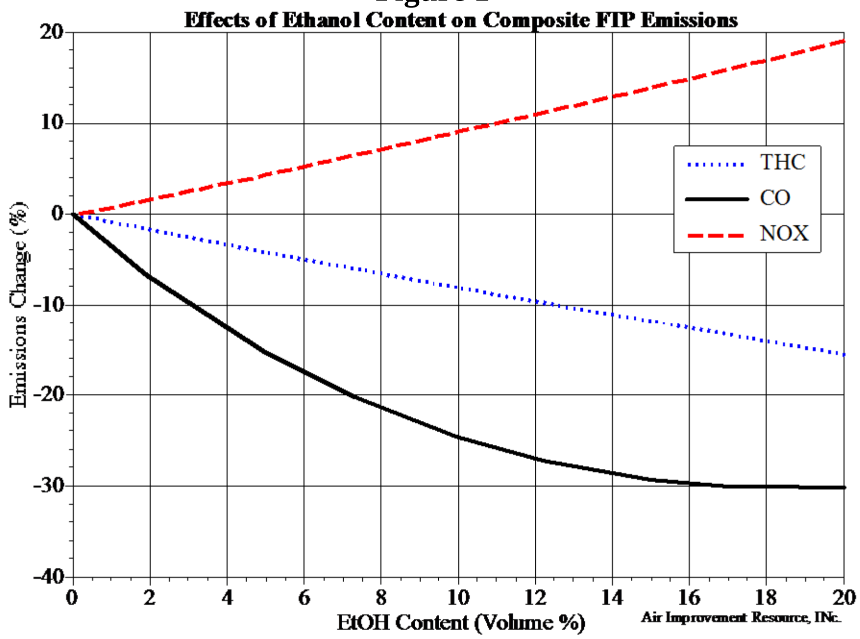


Figure 2

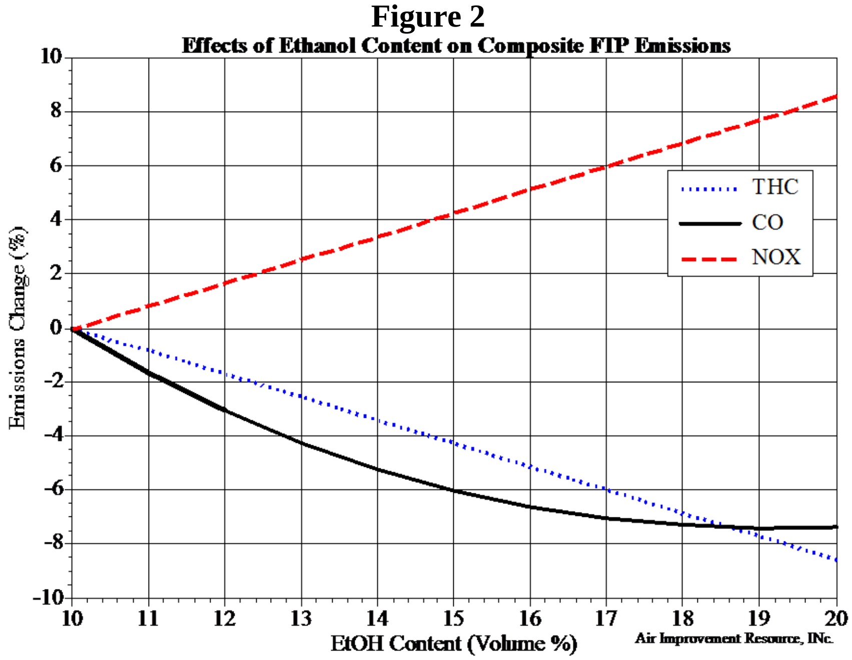


Table 1 shows the composite FTP emissions at 75F of the 2001 and later vehicles. Between E10 and E20, for all the vehicles, NOx emissions increase by 17%, NMHC emission decline by 14%, and CO emissions decline by 19%. Vehicles 7 and 12 have NOx that appear to be particularly sensitive to ethanol; without these vehicles, NOx emissions decline by 4% (with little change in the NMHC and CO trends), instead of increasing by 17%.

Table 1. Composite FTP Emissions on E10 and E20 of 2001 and Later E74b Vehicles

	NOx Emissions, g/mi			NMHC Emissions, g/mi			CO Emissions, g/mi		
Veh No	10%	20%	Ratio, 20/10	10%	20%	Ratio, 20/10	10%	20%	Ratio, 20/10
5	0.176	0.139	0.79	0.071	0.064	0.90	0.99	1.04	1.05
6	0.182	0.176	0.97	0.049	0.051	1.04	1.94	1.54	0.79
7	**0.296**	**0.506**	**1.71**	**0.066**	**0.051**	**0.77**	**0.57**	**0.35**	**0.61**
8	0.182	0.185	1.02	0.084	0.058	0.69	0.52	0.44	0.85
9	0.048	0.058	1.21	0.036	0.023	0.64	0.36	0.28	0.78
10	0.045	0.027	0.60	0.054	0.044	0.81	0.5	0.52	1.04
11	0.046	0.037	0.80	0.024	0.024	1.00	0.15	0.18	1.20
12	**0.046**	**0.089**	**1.93**	**0.03**	**0.023**	**0.77**	**0.23**	**0.06**	**0.26**
13	0.099	0.11	1.11	0.054	0.056	1.04	0.68	0.66	0.97
14	0.048	0.057	1.19	0.037	0.034	0.92	0.2	0.017	0.09
15	0.055	0.05	0.91	0.024	0.026	1.08	0.14	0.023	0.16
All	0.111	0.130	1.17	0.048	0.041	0.86	0.571	0.465	0.81
w/o 7&12	0.098	0.093	0.955	0.048	0.042	0.903	0.609	0.522	0.770

For all vehicles, NOx is 0.019 g/mi higher on E20 than E10, and NMHC is 0.006 g/mi lower on E20 than E10. CO is 0.087 g/mi lower on E20 than E10. If CO is about 1/10 as reactive as NMHC, then the effective NMHC reduction is 0.015 g/mi, with a NOx increase of about 0.019. Thus, based on these data alone, the implementation of E15 for 2001 and later vehicles is not likely to increase or reduce ozone levels.

Since there are no E15 tests in this dataset, it is difficult to determine the changes in emissions between E10 and E15. But the dataset does indicate that HC and CO emissions would be lower, and NOx higher at E15 as compared to E10.

4.2 DOE Study of Intermediate Blends on Legacy Vehicles

The second study is DOE's analysis of the effects of intermediate ethanol blends on legacy vehicles. [9] In this study, twelve 2001 and later vehicles were tested on four splash-blended ethanol fuels with ethanol volume concentrations of E0, E10, E15, and E20. Test vehicles and test fuel properties are shown in Attachment 2. The RVP of he E0 was 9 psi, with the RVPs of the ethanol blends higher at between 9.63 and 9.81 psi. The sulfur level of the E0 was not given, but since the ethanol blends were splash-blended, then the sulfur levels of the ethanol would be lower than the E0. The lower sulfur levels of the ethanol blends would lead to somewhat lower NMHC, CO, and NOx emissions for the ethanol blends due to sulfur's effect on tailpipe emissions. The driving cycle used in this program was the LA-92.

Individual vehicle results for just the 2001 and later vehicles from this testing program are shown in Attachment 3, and plotted for NMHC, CO, and NOx in Figures 3-5.

Figure 3 shows a reduction in NMHC with an increase in ethanol concentration. The average and predicted values at each ethanol level are shown in Table 2 (the predicted values are the ones indicated by the linear regressions).

The individual average values show no difference in NMHC levels between E10 and E15, but the overall trend in using all of the data is lower NMHC emissions with higher ethanol.

Figure 3

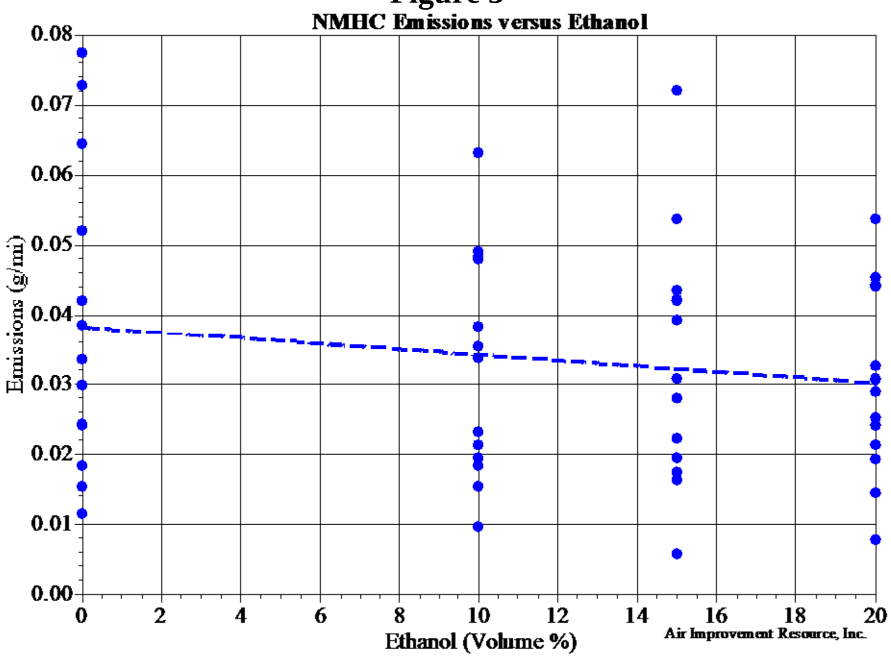


Table 2. Average and Predicted NMHC Values (g/mi)		
Ethanol Level	Average	Predicted
E0	0.039	0.038
E10	0.033	0.034
E15	0.033	0.032
E20	0.030	0.030

CO emissions are shown in Figure 4 and Table 3. The average CO values are shown below.

Table 3. Average and Predicted CO Values (g/mi)

Ethanol Level	Average	Predicted
E0	1.41	1.36
E10	1.26	1.32
E15	1.23	1.30
E20	1.36	1.28

Figure 4 shows that CO is also reduced with increasing ethanol content. The average values show an uptick in CO emissions at E20 relative to E15.

Figure 4

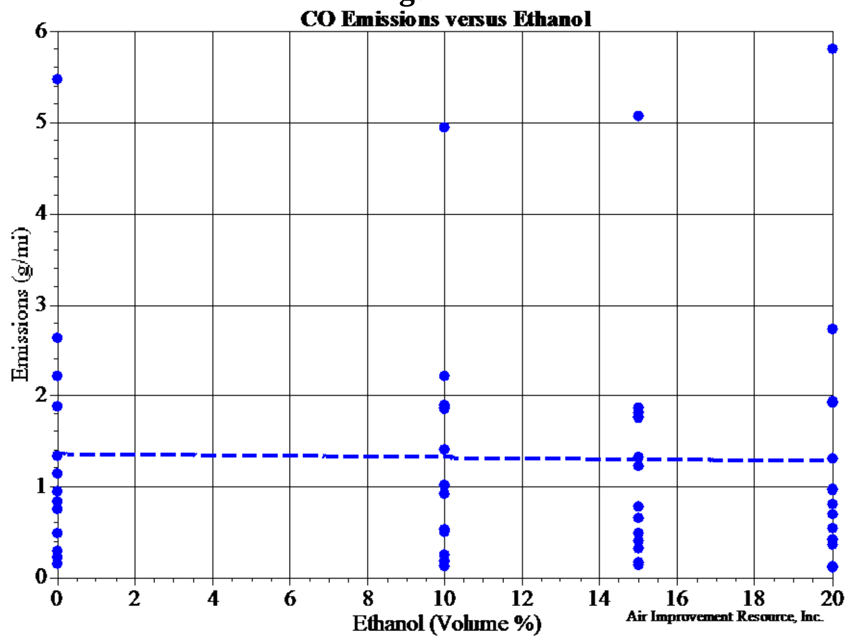


Figure 5 shows the data and trend for NOx. The trend in NOx is down with increasing ethanol content. However, the average values at E15 and E20 are slightly higher than at E10.

Figure 5

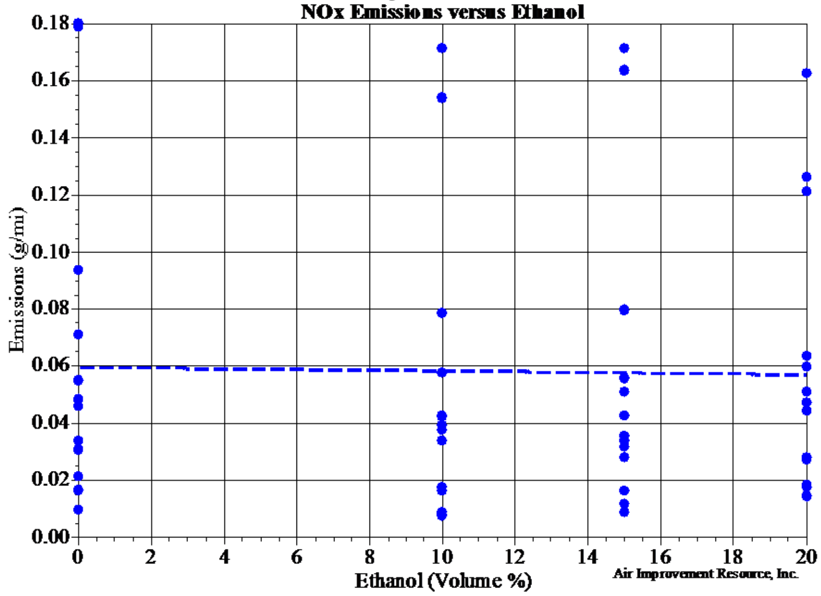


Table 4. Average and Predicted NOx Values (g/mi)		
Ethanol Level	Average	Predicted
E0	0.62	0.60
E10	0.54	0.58
E15	0.56	0.58
E20	0.60	0.57

Overall, these data on intermediate blends show a reduction in NMHC and CO emissions between E10 and E15, and little or no change in NOx.

4.3 DOE Catalyst Study

EPA's E15 waiver docket contained a number of spreadsheets that contained E0, E10, E15 and E20 data on pre-Tier 2 and Tier 2 vehicles that were used to make the E15 decision. [10]. These vehicles were tested in one of two possible testing programs – a Department of Energy (DOE) program conducted by the National Renewable Energy Laboratory (NREL), and at Southwest Research under the EPA EPACT testing program. Vehicle information is found in Attachment 4.

The fuels used at the several test sites were obtained commercially by the subcontractors. In all cases, for both emissions certification and aging fuels, the ethanol-containing fuels were splash-blended. [11]

Emissions and related tests were conducted using emissions certification gasoline (E0) or E15 blended from emissions certification gasoline and denatured fuel-grade ethanol. These batches were subsequently analyzed to provide the information necessary to conduct the program. These analyses included: the actual ethanol content of the batch; carbon; hydrogen and oxygen fractions; and, density. Whenever possible, large enough batches to complete the several phases of the program were produced to reduce potential batch-to-batch effects on the results of the program.

Aging fuels were produced by blending denatured fuel-grade ethanol with gasoline (E0) commercially available at retail stations, rather than emissions certification gasoline, in order to control costs. (Many thousands of gallons of aging fuel were used in the program.) Batches of E15 used for vehicle aging were analyzed for assurance that they contained the correct amount of ethanol. These fuels were not, in general, subjected to the same level of analysis that was required for the emissions test fuels at these sites.

The vehicles were subjected to an initial emission test (FTP) to assure that they were emissions-compliant before acceptance into the program. Once in the program, vehicles were subjected to emissions and related tests at the beginning of mileage accumulation, at least one mid-mileage point, and at the end of mileage accumulation.

Tier 2 compliant vehicles were driven up to their statutory full useful-life (120,000 miles). The initial mileages of the Tier 2 vehicles were about 50,000 miles or lower, meaning that these vehicles were driven approximately 70,000-120,000 miles during the program. Emission intervals were determined based in part on the initial mileage of the vehicles.

The standard road cycle (SRC) was used for all aging. The SRC is the official EPA driving cycle used for aging in the whole vehicle exhaust durability procedure. This cycle has an average speed of 46.3 mph and a maximum speed of 75 mph. During mileage accumulation, recommended scheduled maintenance was performed.

The overall purpose of this testing program was to determine if vehicles would exceed their emission standards at useful life if operated on fuels with ethanol contents higher than E10. A wide array of late model vehicles was selected for the testing program. Several vehicles of each model year and make were purchased. The vehicles were all tested on E0 first to ensure that they were in proper operating conditions. Then, they were segregated by the type of fuel that they would accumulate mileage on. Vehicles accumulated mileage on E0, or E10, or E15, or E20, and then were tested at 3 mileage intervals on different ethanol fuels. Table 5 shows the matrix of mileage accumulation and test fuels for different vehicles.

Table 5. Road and Test Ethanol Fuels

Vehicle	Emissions Group	Road and Test Ethanol Levels					
		Road E0	Road E10	Road E15		Road E20	
		Test E0	Test E0	Test E0	Test E15	Test E0	Test E20
2000 Chevrolet Silverado	PreTier2	*		*	*	*	*
2000 Ford Focus	PreTier2	*		*	*		
2000 Honda Accord	PreTier2	*		*	*		
2002 Dodge Durango	PreTier2	*		*	*	*	*
2002 Nissan Frontier	PreTier2	*		*	*	*	*
2003 Chevrolet Cavalier	PreTier2	*		*	*		
2003 Ford Taurus	Tier2	*		*	*	*	*
2003 Toyota Camry	PreTier2	*		*	*	*	*
2005 Ford F150	Tier2	*		*	*		
2005 Toyota Tundra	Tier2	*		*	*		
2006 Chevrolet Cobalt	Tier2	*		*	*	*	*
2006 Chevrolet Impala	Tier2	*		*	*		
2006 Chevrolet Silverado	Tier2	*	*	*	*	*	*
2006 Ford F150	Tier2						
2006 Nissan Quest	Tier2						
2007 Dodge Caliber	Tier2	*		*	*		
2007 Dodge Caravan	Tier2	*	*	*	*	*	*
2007 Honda Accord	Tier2	*	*	*	*	*	*
2008 Ford Taurus	Tier2	*	*	*	*	*	*
2008 Nissan Altima	Tier2	*	*	*	*	*	*
2009 Ford Explorer	Tier2	*		*	*	*	
2009 Ford Focus	Tier2	*		*	*		
2009 Honda Civic	Tier2	*		*	*	*	
2009 Honda Odyssey	Tier2	*		*	*		
2009 Jeep Liberty	Tier2	*		*	*		
2009 Saturn Outlook	Tier2	*		*	*		
2009 Toyota Camry	Tier2	*		*	*		
2009 Toyota Corolla	Tier2	*		*	*	*	

As the table above indicates, vehicles that accumulated miles on E0 were only tested on E0. Vehicles that accumulated mileage on E10, were also only tested on E10. Vehicles that accumulated mileage on E15 were tested in E0 and E15. Finally, vehicles that accumulated mileage on E20 were tested on both E0 and E20. Thus, there are no vehicles in this testing program that were tested on E10 and E15, or even E10 and E20 (that would allow interpolation between those two endpoints).

Another factor is that the vehicles that accumulated mileage on one fuel were different than the vehicles that accumulated mileage on other fuels, even though they were identical makes, models, and model years. Thus, the only samples it makes sense to examine are the road tested E15 and E20 samples, to determine if the E15 (or E20) results are different than E0. We cannot, however, determine if these would be different from E10.

As a part of the E15 waiver analysis, EPA examined all of the data, and determined that there was no significant difference in deterioration between the different mileage accumulation fuels. As the final rule for 2001-2006 vehicles indicates:

> Overall, the test results for MY2001-2006 are similar to DOE test results for MY2007 and newer light duty motor vehicles, indicating that the earlier model year vehicles are more like later model year vehicles in their ability to maintain emission control performance when operated on E15. The DOE test results strongly confirm EPA's engineering assessment that auto manufacturers responded to regulatory changes applicable to MY2001-2006 with design changes that made light duty motor vehicles capable of maintaining exhaust emissions performance when operated on mid-level gasoline-ethanol blends, up to and including E15.

As a result, this analysis combines all of the emission tests at different mileages for a vehicle for each mileage accumulation fuel. For example, If Vehicle 1 accumulated mileage on E20, but was tested at 3 different mileages on both E0 and E20, this analysis averaged the three different mileage results for E0 into a single average. The same was done for E20.

NMHC CO, and NOx emissions at E0 and E15 are shown in Figures 6, 7, and 8. For NMHC and CO, emissions are decreased at E15 over E0. For NOx, there is a slight increase between E0 and E15. The average values at E0 and E15 are shown in Table 6.

Figure 6

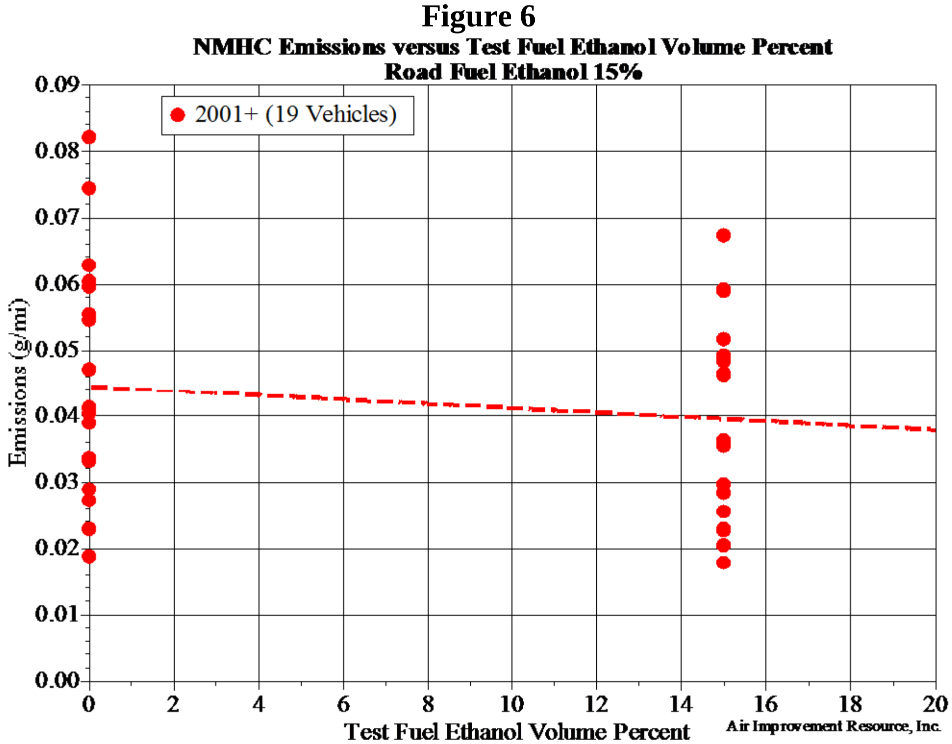


Figure 7

CO Emissions versus Test Fuel Ethanol Volume Percent

Road Fuel Ethanol 15%

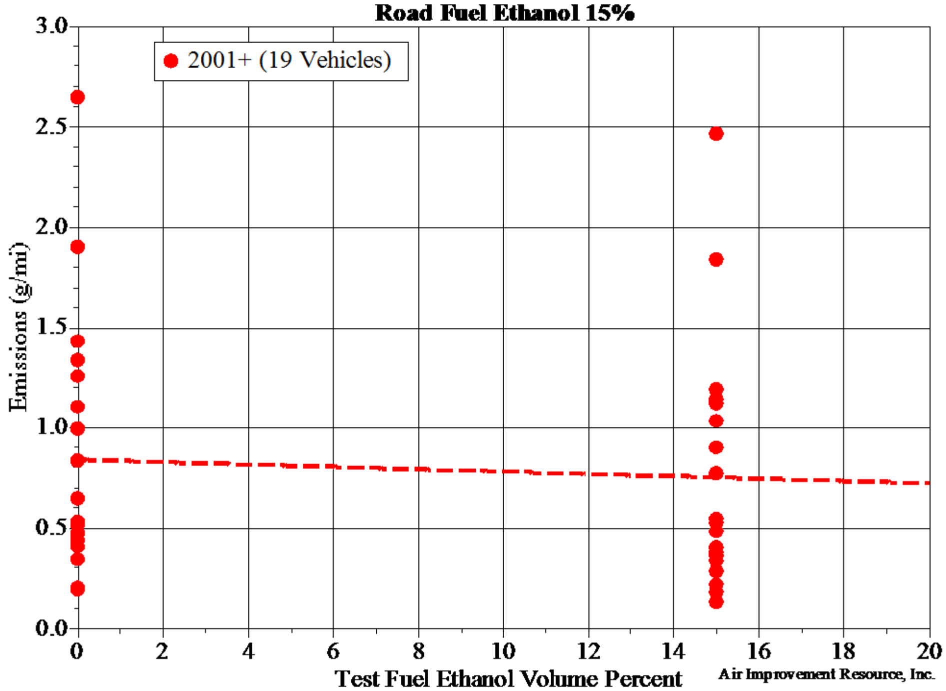
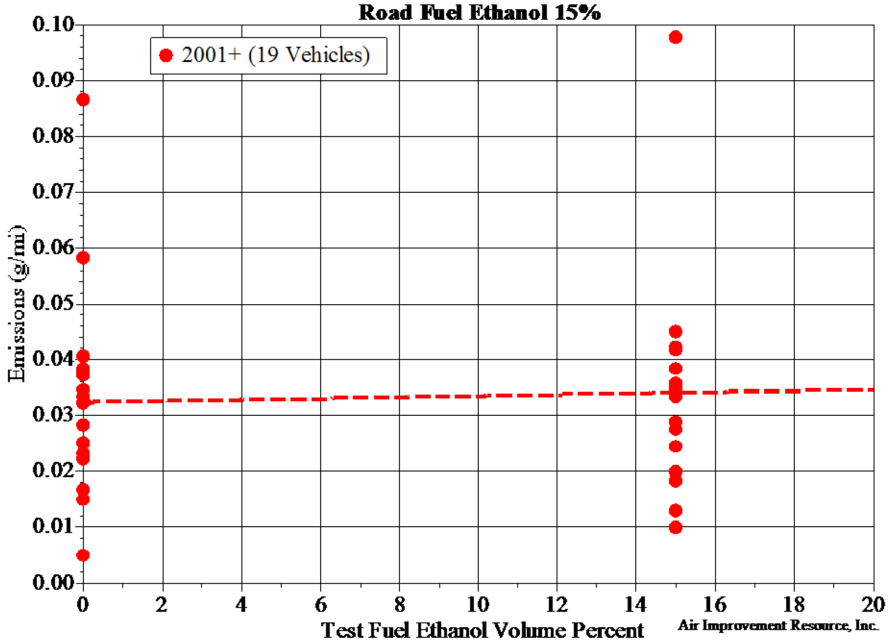


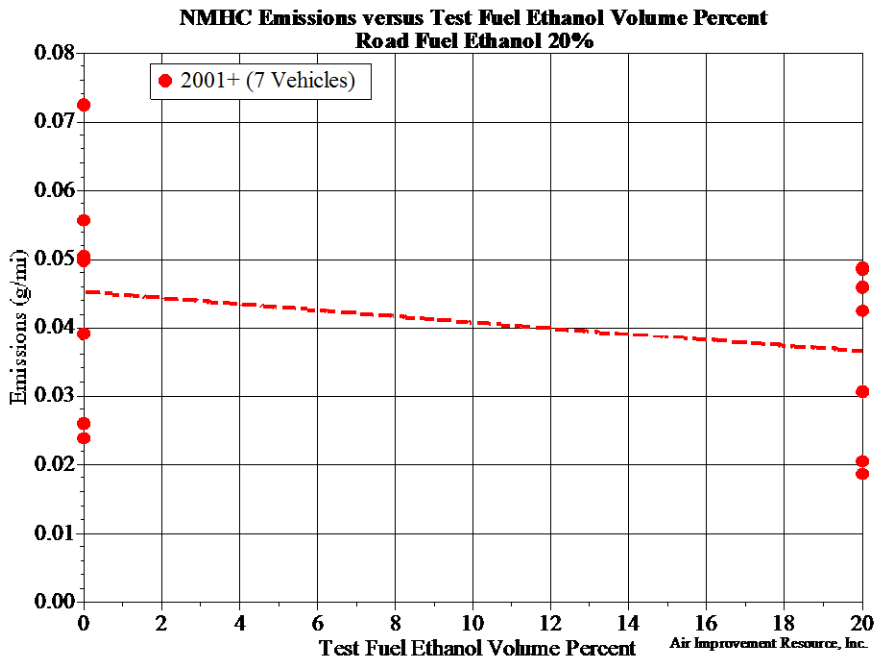
Figure 8

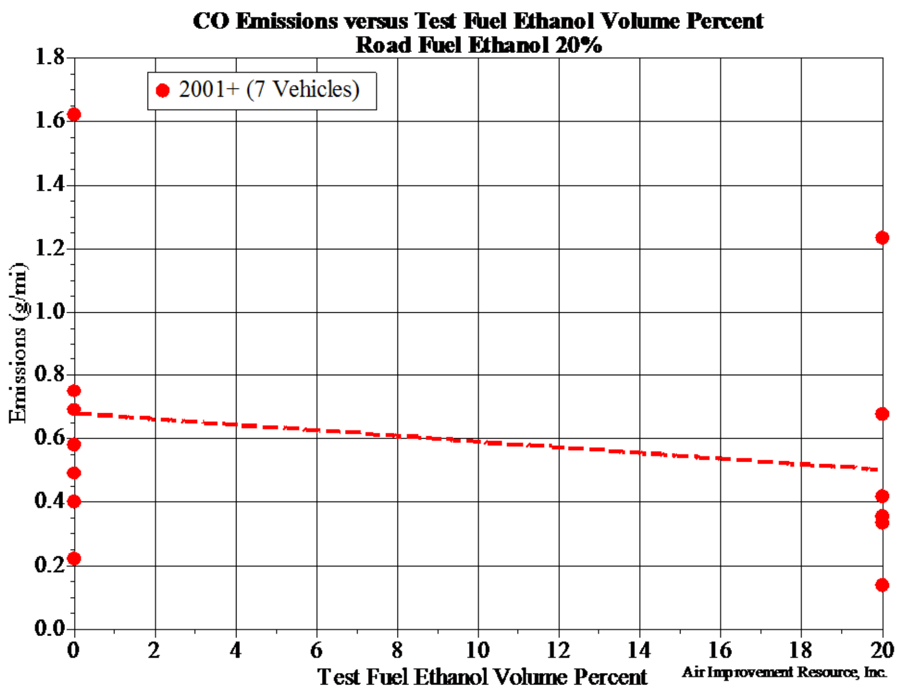
NOx Emissions versus Test Fuel Ethanol Volume Percent

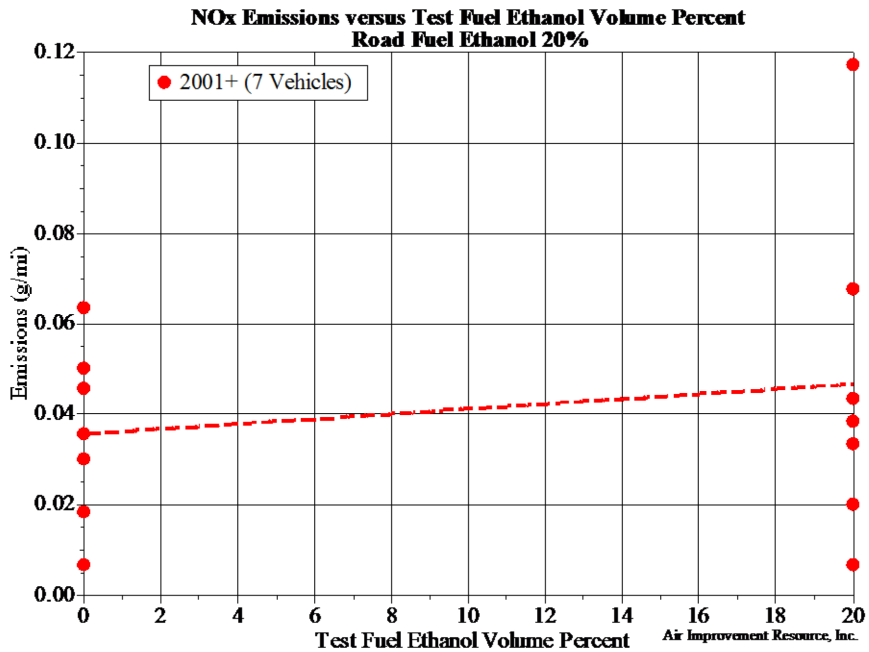
Road Fuel Ethanol 15%



Figures 9-11 show the emissions at E0 and E20 for the vehicles that accumulated mileage on E20. There are reductions in NMHC and CO, and an increase in NOx.


NMHC Emissions versus Test Fuel Ethanol Volume Percent
Road Fuel Ethanol 20%
2001+ (7 Vehicles)
Emissions (g/mi)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
2
4
6
8
10
12
14
16
18
20
Test Fuel Ethanol Volume Percent
Air Improvement Resource, Inc.


CO Emissions versus Test Fuel Ethanol Volume Percent
Road Fuel Ethanol 20%
2001+ (7 Vehicles)
Emissions (g/mi)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
2
4
6
8
10
12
14
16
18
20
Test Fuel Ethanol Volume Percent
Air Improvement Resource, Inc.



Average emissions for both mileage accumulation fuels are shown in Table 6.

Table 6. Average Emissions in DOE Catalyst Study

		Average Emissions (g/mi)		
Road Ethanol	Pollutant	E0	E15	E20
E15	NMHC	0.045	0.040	
	CO	0.841	0.753	
	NOx	0.032	0.034	
E20	NMHC	0.045		0.037
	CO	0.679		0.502
	NOx	0.036		0.047

Overall, this study indicates possible reductions in NMHC and CO emissions, with either no change in NOx or a small increase in NOx.

4.4 Summary of Exhaust Impacts from E10 to E15

On balance, these studies indicate a reduction in NMHC and CO emissions between E10 and E15, with either a small increase in NOx or no change in NOx. But clearly, the data are sketchy between E10 and E15. Two of the three studies utilized splash-blended fuels, and one utilized a match-blended fuel. The one match-blended fuel study did not show different results from the splash-blended fuel studies.

5.0 Evaporative Emissions

Evaporative hydrocarbon emissions from gasoline vehicles come from three basic sources – permeation, vapor escapes, and liquid leaks. Permeation is the process where fuel can gradually migrate through fuel system components, such as fuel lines and fuel vapor hoses. Fuel vapor can escape if there is a leak in a fuel vapor line, fuel filler inlet, at the upper part of the fuel tank, or outside of the canister. Liquid leaks can occur if there is a leak in a fuel hose or the fuel tank. Vehicles with liquid leaks are quite rare, but understandably they have very high emissions. Ethanol would have no effect on the emissions of vehicles with liquid leaks.

Model year 1996 and later model year vehicles have very sophisticated control systems to eliminate vapor emissions from the fuel system. The central emission control component in these systems is the canister that is filled with activated charcoal, to absorb gasoline vapor from the fuel tank when a vehicle is parked and the ambient temperature is rising, causing expansion of vapor in the vehicle's fuel tank. This stored vapor is then burned in the engine when the vehicle is driven. Vapor emissions only occur in late model vehicles when there is a vapor leak somewhere in this vapor control system, or a car is parked too long (many days) without being operated, causing the canister to become "saturated", and excess vapor to be released from the canister. The quantity of vapor coming from the fuel tank is related to the temperature increase in the tank, and the volatility of the fuel.

Ethanol increases the volatility of gasoline when added, but the maximum increase in vapor pressure is below 10% ethanol by volume. At ethanol levels above E10, gasoline volatility actually drops.

The RFS has resulted in nearly all gasoline containing 10% ethanol by volume. EPA provides for a 1 psi waiver during the summer months, which many states recognize through their own regulations. The vapor emissions from vehicles and equipment with these fuels are higher than they would be without a 1 psi waiver. As stated in the Background section, E15 is not allowed a 1 psi waiver. If a state with an E10 mandate and a 1 psi waiver were to switch over to using E15 for all of its 2001 and later vehicles (but retain E10 for all 2000 and earlier vehicles and all off-road equipment), the vapor emissions from the 2001 and later vehicles would be somewhat lower than if these vehicles continued to use E10 with a 1 psi waiver. The emission benefit for this switch would be a function of the difference in vapor emissions for 2001 and later vehicles, and the penetration of E15 in the 2001 and later fleet. We will make an estimate of the upper limit of this emission benefit later in this section.

Ethanol does have an effect on permeation emissions from motor vehicles. There have been two testing programs that have evaluated permeation emissions from motor vehicle fuel systems at varying ethanol levels, including ethanol blends above E10. The two testing programs are the CRC E-65-3 testing program, and the CRC E-77-2 testing program. [12, 13] The remainder of this section discusses the E-65-3 program, then the E-77-2 program, and then these programs are summarized. This is followed by a discussion of the benefits of 2001 and later vehicles switching to E15 in a state that has a 1 psi RVP waiver.

5.1 CRC E-65-3

This test program conducted diurnal permeation testing on the fuel systems of the five vehicles shown in Table 7. Two vehicles met the federal Enhanced Evaporative Emission Standards of 2 g/day (sum of 3rd-day diurnal and hot soak tests), one met the California Near Zero Standard of 0.5 g/day (also sum of 3rd day diurnal and hot soak tests), one was a California Partial Zero Emissions Vehicle (PZEV) with zero fuel emissions, and the last was a Flexible Fuel Vehicle (FFV).

The complete fuel systems were removed from the vehicles and installed on a test rig that maintained all components in the same configuration as they were on the vehicle. These systems were preconditioned with the fuel to be tested on for a period of time, and then tested on each fuel. Five fuels were used in the testing program:

- E0
- E6
- E6 high aromatics
- E10
- E20

All fuels had a fuel volatility of between 7.0 and 7.25 psi. There was no E15 tested in this testing program.

Not all vehicles were tested on the E6 and E6 with high aromatics, but all vehicles were tested on E0, E10 and E20. Vehicles were tested on a 24-hour diurnal test in a Variable Temperature Sealed Housing Evaporative Determination (VT-SHED) using ambient temperatures from 65° F to 105° F and back to 65° F. This is the temperature range required in the California Enhanced Evaporative Testing regulations, and would result in higher emissions than the Federal Enhanced Evaporative testing (which utilizes a 72-96-72 profile) at the same fuel volatility (permeation emissions approximately double with each 10° C increase in temperature). The canisters' vent lines were routed outside the SHED so that only permeation emissions would be measured inside the SHED.

Table 7. E-65-3 Test Rigs

Test Rig	Model Year	Make	Model	Tank Size	Tank Material	Evaporative Technology
1	2001	Toyota	Tacoma	15.8	Metal	Enhanced
2	2000	Honda	Odyssey	20	Plastic	Enhanced
11	2004	Ford	Taurus	18	Metal	Ca Near Zero
12	2004	Chrysler	Sebring	16	Metal	Ca PZEV (Zero fuel evap)
14	2005	Chevrolet	Tahoe	26	Plastic	FFV

Test results in mg/day for the five vehicles on E0, E10 and E20 are shown in Table 8. Vehicles 1, 2, and 12 had higher permeation emissions on E20 than on E10. However, two of the five vehicles, the California Near Zero vehicle and the FFV, experienced lower permeation emissions on E20 than on E10. On average, permeation VOC emissions are 16% higher on E20 than E10. While these data seem to indicate that permeation emissions could be higher on E20 than on E10, it is by no means conclusive, based on these data alone.[5] Also, since no E15 was utilized in this testing program, it is not clear what the results would have been on E15.

Table 8. Diurnal VOC Permeation Test Results (mg/day)

Rig	E0	E10	E20
1	91	468	508
2	458	1301	1765
11	39	123	102
12	36	64	75
14	261	466	360
Average	177	484	562

5.2 CRC E-77-2

This testing program tested eight vehicles. One was a pre-enhanced vehicle, five were "Enhanced Evaporative" vehicles, and two were "Tier 2" Near Zero vehicles. The eight vehicles are shown in Table 9.

Table 9. Test Vehicles in CRC E-77-2

Vehicle Number	Model Year	Make	Model	Evap Standard	Fuel Tank
202	1996	Ford	Taurus	Pre-enhanced	Metal
204	1999	Honda	Accord	Enhanced/ORVR	Metal
205	2001	Toyota	Corolla	Enhanced/ORVR	Metal
207	2001	Dodge	Caravan	Enhanced/ORVR	Plastic
214	2004	Ford	Escape	Enhanced/ORVR	Plastic
215	2004	Toyota	Highlander	Enhanced/ORVR	Plastic
211	2004	Toyota	Camry	Near Zero/ORVR	Plastic
212	2006	Ford	Taurus	Near Zero/ORVR	Metal

The test fuel target ethanol concentrations and fuel volatility values are shown in Table 10. The table shows that at 9 psi, vehicles were tested on both E0 and E20, but not at E10. The E10 tests were conducted at 7 psi and 10 psi. Ideally we would like to compare E10 with E20 with the same RVP, and we do not know what effect RVP has on

[5] There is no question whether permeation emissions with either E10 or E20 are higher than E0, as all five vehicles experienced a significant increase in permeation emissions between E0 and either E10 or E20.

permeation. We can, however, average the E10 7 psi and 10 psi results. The average of these two volatilities is 8.5 psi, which is close to the 9 psi E20 results.[6]

Table 10. Test Fuel Targets			
Ethanol Level	7 psi	9 psi	10 psi
E0	X	X	
E10	X		X
E20		X	

The protocols adopted for this test program were to require a minimum of four weeks of vehicle exposure to a new fuel when first introducing 10 or 20 volume percent to the vehicle, and one week for a change in RVP.

Vehicle permeation emissions were determined in a VT-SHED. Tank venting losses were isolated from permeation emissions by routing the vehicle's canister vent (via a very low permeation hose) to a separate trap canister located outside of the SHED.

Four types of tests were performed:

- Static permeation rate testing
- Running loss test
- Hot soak
- Diurnal test

The static permeation rate testing was performed at a temperature of 86° F for one hour. The running loss testing utilized two cycles of he LA-92 test (48 minutes total), at a temperature of 86° F. The hot soak test is performed immediately following the running loss test for 1 hour. In the diurnal test, the vehicle fuel tanks is filled to 40% full, and after preconditioning, the California 3-day test is performed using ambient temperatures of 65°-105° F. This temperature range is the range required in the California Enhanced Evaporative test, and is even higher than the range of the Federal test. As a result, the permeation impacts should be viewed as "worse-case", and not typical results.

Static permeation results are shown in Table 11. Three sets of results are shown – the 7psi E10 values, the 10 psi E10 values, and 9 psi E20 values. The average of all of these vehicles is also shown. The 10 psi E10 average results are slightly higher than the 7 psi E10 results, and the E20 results are 8% higher than the average of average of the 7 psi and 10 psi E10 results. Vehicle 211 appears to be very sensitive to ethanol. The other vehicles appear to be much less sensitive, with some registering increases for E20 and some registering decreases in emissions.

[6] While the target level of the 9 RVP was 9, it actually tested at 8.5, and was used in the program.

Table 11. Static Permeation Test Results (mg/hr)					
Vehicle	Tech	Tank	7 psi E10	10 psi E10	9 psi E20
204	Enhanced	Metal	66.4	84.3	55.3
205	Enhanced	Metal	59.6	41.6	46.2
297	Enhanced	Plastic	64.4	78.7	88.2
214	Enhanced	Plastic	23.9	24.4	16.8
215	Enhanced	Plastic	12.2	10.4	19.3
211	Near Zero	Plastic	9.4	19.9	55.8
212	Near Zero	Metal	21.8	10.6	4.7
	Average of all		36.8	38.6	40.9
	Average, 7 psi E10 and 10 psi E10		37.7		

Running loss permeation results are shown in Table 12. The E20 results are 23% higher than the average of all E10 results. Again, vehicle 211 appears to be very sensitive to ethanol, with the other vehicles being much less sensitive.

Table 12. Running Loss Permeation Test Results (mg/hr)					
Vehicle	Tech	Tank	7 psi E10	10 psi E10	9 psi E20
204	Enhanced	Metal	287.9	316.4	272.0
205	Enhanced	Metal	232.8	191.6	169.7
297	Enhanced	Plastic	812.2	858.1	1028.2
214	Enhanced	Plastic	105.7	133.1	139.4
215	Enhanced	Plastic	97.9	71.9	102.5
211	Near Zero	Plastic	56.3	138.3	410.6
212	Near Zero	Metal	201.2	148.9	116.8
	Average of all		256.3	265.5	319.9
	Average, 7 psi E10 and 10 psi E10		260.9		

Hot soak permeation results are shown in Table 13. The E20 results are lower than the average of all E10 results.

Table 13. Hot Soak Permeation Test Results (mg/hr)					
Vehicle	Tech	Tank	7 psi E10	10 psi E10	9 psi E20
204	Enhanced	Metal	29.7	0.4	13.4
205	Enhanced	Metal	71.9	29.5	60.3
297	Enhanced	Plastic	122.2	237.7	0
214	Enhanced	Plastic	32.9	57.4	56
215	Enhanced	Plastic	0	1.6	0
211	Near Zero	Plastic	13.8	0	0
212	Near Zero	Metal	0	0	4.9
	Average of all		38.6	46.7	19.2
	Average, 7 psi E10 and 10 psi E10		42.7		

Diurnal permeation results (for the first day of the 3-day diurnal test) are shown in Table 14. The numbers are significantly higher than the previous numbers because the units on these values are in mg/day instead of mg/hr. The values for 10 psi E10 are higher than 7 psi E10, but the average values for E20 are essentially equivalent to the average of all E10 values (1.1% difference).

Table 14. Diurnal Permeation Test Results (mg/day)					
Vehicle	Tech	Tank	7 psi E10	10 psi E10	9 psi E20
204	Enhanced	Metal	1260.1	1547.9	1103.4
205	Enhanced	Metal	1783.4	1794.1	1775.2
297	Enhanced	Plastic	1086.5	1406.4	1548.0
214	Enhanced	Plastic	524.2	492.0	470.9
215	Enhanced	Plastic	224.7	319.2	416.8
211	Near Zero	Plastic	243.8	337.0	284.0
212	Near Zero	Metal	184.8	124.3	131.0
	Average of all		758.2	860.1	818.5
	Average, 7 psi E10 and 10 psi E10		809.2		

5.3 Summary of Evaporative Test Results

The CRC E65-3 testing program showed that diurnal E20 permeation emissions are 16% higher than E10. There was no testing on E15. The CRC E77-2 program showed no impact of E20 relative to E10 for diurnal results, lower results for E20 compared to E10 for hot soak, and higher results for E20 compared to E10 for running losses. This testing program also did not evaluate E15 as compared to E10.

Overall, based on the running loss results, the static results from E-77-2, and the diurnal test results from both testing programs, permeation emissions could be a little higher for E20 as compared to E10. However, without a clear trend in these results between E10 and E20, it is difficult for us to interpolate between E10 and E20 and conclude what the

E15 results would be relative to E10. Until additional data on E15 becomes available, this analysis concludes that there is no difference in permeation VOC emissions between E10 and E15. With respect to the other evaporative components, with some a little higher and some a little lower, we conclude that there is no overall change in evaporative emissions between E10 and E15.

This study also examined the impact of a state with a 1 psi waiver for ethanol switching from E10 for all 2001 and later vehicles to E15. As noted earlier, under the terms of the E15 waiver, E15 is not eligible for a 1 psi waiver. Thus, a state with E10 and a 1 psi waiver for ethanol will have reduced RVP for 2001 and later vehicles if it switches to E15 for these vehicles.

For this analysis, we chose the state of Minnesota. Minnesota has had E10 for a number of years, with a 1 psi waiver for ethanol. The EPA MOVES2010 model was used for this analysis. The MOVES model uses a value of 9.7 RVP for all counties in Minnesota, which reflects a 9 psi level for gasoline not containing ethanol, with the addition of the 1 psi waiver and a 0.3 psi expected margin. All on-road gasoline vehicles were examined.

The analysis year selected was 2020. In 2020, 90% of the vehicle miles traveled is due to 2001 and later vehicles, so the percent benefit for this year should be an upper limit of the benefit on 2001 and later vehicles, since there are a few vehicles that are pre-2001 in 2020. The MOVES model assumed RVP of 9.7 was reduced to 8.7 for all counties, and emissions were estimated for July, both before and after adjustment. Table 15 shows the results of this analysis. The MOVES model predicts that both exhaust and evaporative VOC emissions would be lower with lower RVP)the table shows the combined effect).

Table 15. Minnesota: MOVES July 2020

RVP of Gasoline	Exhaust+Evap VOC Emissions from All Gasoline Vehicles (Short Tons/Day)
9.7 (Current)	4.392
8.7 (2001 with E15)	4.264
Difference (%)	0.128 (2.9%)

Results show that switching to E15 would reduce VOC emissions by 2.9% in 2020. The benefit in 2011 would be somewhat less than this (approximately one-half), since the percent of 2001 and later vehicles in calendar year 2011 is smaller than in 2020.

The above benefit would only exist in states or areas with a 1 psi waiver for E10, and not in states or areas where E10 is not granted a 1 psi waiver.

6.0 Overall Impacts of E15 on 2001 and Later Vehicles

Within the reviewed data set, the exhaust emission studies indicate a reduction in NMHC and CO emissions between E10 and E15, with either a small increase in NOx or no change in NOx. Permeation evaporative emissions data exists for E10 and E20 fuels that can be used to show directionally what the E15 results would be relative to E10. With this limited data, this analysis concludes that there is no difference in permeation of VOC emissions between E10 and E15. Evaporative emissions would be reduced in states or areas with a 1 psi waiver for E10 that switch from E10 to E15.

References

1. CFR Volume 75, No 58, March 26, 2010, "Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Final Rule" (14669-14904)

2. CFR Volume 76, No 213, November 4, 2010, "Partial Grant and Partial Denial of Clean Air Act Waiver Application Submitted by Growth Energy To Increase the Allowable Ethanol Content of Gasoline to 15 Percent; Decision of the Administrator; Notice" (68093-68150).

3. CFR Volume 76, No 17, January 26, 2011, "Partial Grant of Clean Air Act Waiver Application Submitted to Growth Energy to Increase the Allowable Ethanol Content of Gasoline to 15 Percent, Decision of the Administrator (4662-4683).

4. "Flexible-Fuel Vehicle and Refueling Infrastructure Requirements Associated with Renewable Fuel Standard (RFS) Implementation", December 16, 2010, AIR, Inc. for RFA.

5. CRC Report No E-84, "Review of Prior Studies of Fuel Effects on Vehicle Emissions", Hochhauser, August 2008.

6. CRC Report No. E-90, "Impact of E15/E20 Blends on OBD II Systems – Pilot Study", de la Torre Klausmeier Consulting, March 9, 2010.

7. CRC Report E-90-2, "Evaluation of Inspection and Maintenance OBD II Data to Identify Vehicles That May Be Sensitive to E10+ Blends", Sierra Research, January 31, 2011.

8. CRC Report No. E-74b, "Effects of Vapor Pressure, Oxygen Content, and Temperature on CO Exhaust Emissions", Coordinating Research Council, May 2009.

9. "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Engines, Report 1-Updated", ORNL, February 2009.

10. The following spreadsheets in the EPA E15 Docket EPA-HQ-OAR-2009-211:

    EPA-HQ-OAR-2009-0211-14002.1.xls
    EPA-HQ-OAR-2009-0211-14017.xls
    EPA-HQ-OAR-2009-0211-14045.1.xls
    EPA-HQ-OAR-2009-0211-14035.1.xlsx
    EPA-HQ-OAR-2009-0211-14052.1.xlsx

11. "Technical Summary of DOE Study on E15 Impacts on Tier 2 Vehicles" Technical Memorandum from Robert Anderson, EPA to Docket EPA-HQ-OAR-2009-211.

12. CRC Report No. E-65-3, "Fuel Permeation From Automotive Systems: E0, E6, E10, E20, and E85", Harold Haskew and Associates and McClement of ATL for Coordinating Research Council, December 2006.

13. CRC Report No. E-77-2, "Enhanced Evaporative Emission Vehicles", Harold Haskew and Associates for Coordinating Research Council, March 2010.

Attachment 1

Vehicle and Test Fuel Specifications from E-74b

Table 3-2
Test Vehicle Emission Certification Classes

Veh No	Model Year	Make	Exhaust Standard	Standards [a] (g/mile)	Cold CO Standards (g/mile)	Evap Standard
001	1994	Chevrolet	Tier 1 LDV	.31/4.2/.6	N/A	Pre Enhanced
002	1996	Ford	Tier 1 LDV	.31/4.2/.7	10.0	Enhanced
003	1995	Jeep	Tier 1 LDT2	.40/5.5/0.97	N/A	Pre Enhanced
004	1999	Honda	NLEV LEV	.09/4.2/.3	10.0	Enhanced/ORVR
005	2001	Toyota	NLEV LEV	.09/4.2/.3	10.0	Enhanced/ORVR
006	2002	Nissan	NLEV ULEV	.055/2.1/.3	10.0	Enhanced/ORVR
007	2001	Dodge	NLEV LEV LDT2	.13/5.5/.5	12.5	Enhanced/ORVR
008	2002	Chevrolet	NLEV LEV LDT2	.13/5.5/.5	12.5	Enhanced/ORVR
009	2004	Dodge	Tier 2 Bin 5	.09/4.2/.07	10.0	Enhanced/ORVR
010	2004	Chevrolet	Tier 2 Bin 5	.09/4.2/.07	10.0	Enhanced/ORVR
011	2004	Toyota	Tier 2 Bin 9	.09/4.2/.30	10.0	Near Zero/ORVR
012	2006	Ford	Tier 2 Bin 5	.09/4.2/.07	10.0	Near Zero/ORVR
013	2004	Dodge	Tier 2 Bin 10 LDT	.23/6.4/.60	12.5	Enhanced/ORVR
014	2004	Ford	Tier 2 Bin 9	.09/4.2/.30	10.0	Near Zero/ORVR
015	2004	Toyota	Tier 2 Bin 5	.09/4.2/.07	10.0	Near Zero/ORVR

Table 3-4
Fuel Properties (Average from sponsors)

Inspection	Units	Fuel 6	Fuel 3	Fuel 5	Fuel 7	Fuel 1	Fuel 2	Fuel 4
API Gravity	°API	60.2	63.3	64.1	58.5	58.8	59.7	57.0
Relative Density	60/60°F	0.7381	0.7262	0.7231	0.7447	0.7435	0.7399	0.7506
DVPE	psi	6.95	9.10	12.76	7.30	8.79	13.30	8.47
Oxygenates--D4815								
MTBE	vol %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ETBE	vol %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EtOH	vol %	0.00	0.00	0.00	9.54	9.42	9.03	20.38
Oxygen	wt %	0.00	0.00	0.00	3.53	3.49	3.36	7.49
HC Composition								
Aromatics	vol %	22.1	23.4	24.2	24.4	23.6	22.5	21.5
Olefins	vol %	8.0	9.6	9.5	8.8	9.6	9.6	10.9
Saturates	vol %	70.0	67.1	66.4	57.3	57.5	59.0	46.8
D86 Distillation								
IBP	°F	99.9	88.8	82.0	104.0	97.2	83.7	103.3
10%	°F	142.4	122.4	106.4	133.0	125.1	107.9	131.2
50%	°F	197.9	191.0	189.1	195.0	189.8	165.4	159.6
90%	°F	313.6	316.5	316.3	317.0	319.0	322.1	313.7
EP	°F	361.0	353.7	353.7	360.0	357.2	352.4	342.0
Recovery	vol %	97.8	97.6	96.6	97.8	97.9	96.7	98.3
Residue	vol %	1.3	1.6	1.3	1.0	1.1	1.4	1.1
Loss	vol %	1.0	0.8	2.1	1.2	1.0	1.7	0.7
Drivability Index	-	1120.7	1073.2	1043.2	1101.5	1075.9	979.9	989.1

Attachment 2

Vehicle and Test Fuel Specifications from Intermediate Effects Report

Table 2.4. Test vehicle list

OEM (make)	Model	Year	Engine	Initial odometer reading (miles)	EPA engine family	Emission standard	Test site	Phase
Chrysler	Town & Country	2007	3.3 L V6	35,000	7CRXT03.8NEO	Tier 2, Bin 5	NREL/CDPHE	A
Ford	F150	2007	5.4 L V8	28,600	7FMXT05.44H7	Tier 2, Bin 8	TRC	A
Ford	F150	2003	5.4 L V8	57,000	3MFXT05.4PFB	Tier 1 LEV	TRC	A
Ford	Taurus	2003	3.0 L V6	89,600	3FMXV03.0VF3	Tier 2, Bin 8	TRC	A
GM (Buick)	Lucerne	2007	3.8 L V6	10,000	7GMXV03.9146	Tier 2, Bin 5 (CA LEV II)	NREL/CDPHE and ORNL[a]	A
GM (Buick)	LeSabre	2003	3.8 L V6	78,000	3GMXV03.8044	Tier 2, Bin 8	NREL/CDPHE	A
GM	Silverado	2007	4.8 L V8	12,800	7GMXT05.3379	Tier 2, Bin 8	TRC	A
Honda	Accord	2007	2.4 L I4	11,400	7HNXV02.4KKC	Tier 2, Bin 5 (CA LEV II)	TRC	A
Nissan	Altima	2003	3.5 L V6	53,300	3NSXV03.5C7A	LEV	TRC	A
Toyota	Camry	2007	2.4 L I4	26,440	7TYXV02.4BEB	Tier 2, Bin 5	ORNL and NREL/CDPHE[a]	A
Toyota	Camry	2003	2.4 L I4	72,800	3TYXV02.4HHA	ULEV	ORNL	A
Chrysler	PT Cruiser	2001	2.4 L I4	93,400	1CRXV02.4VD0	NLEV	NREL/CDPHE	B
Ford	Crown Victoria	1999	4.6 L V8	50,900	XFMXV04.6VBE	ULEV	NREL/CDPHE	B
Honda	Civic	1999	1.6 L I4	79,680	XHNXV01.6TA3	Tier 1	ORNL	B
Toyota	Corolla	1999	1.8 L I4	96,400	XTYXV01.8XBA	Tier 1	NREL/CDPHE	B
VW	Golf GTI	2004	1.8 L I4 Turbo	32,900	4ADXV01.8356	Tier 2, Bin 8	ORNL	B

[a]Round-robin vehicle tested at two sites; abbreviations: LEV = low-emissions vehicle, NLEV = National Low Emission Vehicle Program vehicle, ULEV = ultra-low-emissions vehicle.

Table 2.2. Test fuel properties

Test laboratory	Fuel	EtOH (vol %)	DVPE (psi)	LHV (Btu/lbm)	SG	C (wt frac)	H (wt frac)	O (wt frac)
NREL	E0	0.0	8.96	18,533	0.746	0.8615	0.1305	0.0000
	E10	9.9	9.81	17,873	0.750	0.8184	0.1237	0.0365
	E15	13.9	9.63	17,471	0.752	0.8072	0.1268	0.0511
	E20	18.6	9.65	17,091	0.754	0.7877	0.1292	0.0679
ORNL	E0	0.0	8.40	18,534	0.746	0.8683	0.1297	0.0000
	E10	9.1	9.48	17,844	0.750	0.8256	0.1262	0.0336
	E15	14.4	9.33	17,485	0.752	0.8016	0.1252	0.0527
	E20	19.8	9.23	17,043	0.755	0.7966	0.1284	0.0723
ANL	E0	0.0	8.49	18,542	0.746	0.8683	0.1285	0.0000
	E10	9.9	9.34	17,793	0.751	0.8229	0.1285	0.0362
	E15	14.3	9.39	17,412	0.752	0.8058	0.1341	0.0524
	E20	19.6	9.15	17,044	0.755	0.7897	0.1271	0.0717

Abbreviations: EtOH = ethanol; DVPE = dry vapor pressure equivalent; LHV = lower heating value; SG = specific gravity; C = carbon; H = hydrogen; O = oxygen.

Attachment 3

Individual Vehicle Results from DOE Intermediate Blends Study

NMHC Emissions (g/mi) versus Ethanol				
Vehicle	E0	E10	E15	E20
2001 Chrysler PT Cruiser	0.024	0.021	0.019	0.025
2003 Buick LeSabre	0.018	0.019	0.022	0.021
2003 Ford F150	0.073	0.063	0.054	0.054
2003 Ford Taurus	0.078	0.048	0.042	0.044
2003 Nissan Altima	0.064	0.049	0.072	0.044
2003 Toyota Camry	0.052	0.048	0.043	0.045
2004 VW Golf GTI	0.015	0.018	0.017	0.019
2007 Buick Lucerne	0.038	0.034	0.031	0.029
2007 Chevrolet Silverado	0.034	0.035	0.039	0.031
2007 Chrysler T&C	0.030	0.023	0.028	0.024
2007 Ford F150	0.042	0.038	0.042	0.033
2007 Honda Accord	0.012	0.010	0.006	0.008
2007 Toyota Camry	0.024	0.015	0.016	0.014
Average	0.039	0.033	0.033	0.030

CO Emissions (g/mi) versus Ethanol				
Vehicle	E0	E10	E15	E20
2001 Chrysler PT Cruiser	1.87	1.89	1.76	1.93
2003 Buick LeSabre	0.29	0.25	0.32	0.37
2003 Ford F150	0.95	0.92	0.78	0.80
2003 Ford Taurus	0.75	0.50	0.41	0.42
2003 Nissan Altima	0.84	0.52	0.65	0.69
2003 Toyota Camry	5.47	4.95	5.07	5.81
2004 VW Golf GTI	0.49	0.53	0.49	0.55
2007 Buick Lucerne	2.21	1.86	1.81	1.91
2007 Chevrolet Silverado	1.34	1.40	1.32	1.31
2007 Chrysler T&C	1.14	1.02	1.23	0.97
2007 Ford F150	2.63	2.21	1.87	2.73
2007 Honda Accord	0.23	0.18	0.14	0.12
2007 Toyota Camry	0.16	0.13	0.16	0.12
Average	1.41	1.26	1.23	1.36

NOx Emissions (g/mi) versus Ethanol				
Vehicle	E0	E10	E15	E20
2001 Chrysler PT Cruiser	0.179	0.171	0.171	0.126
2003 Buick LeSabre	0.055	0.034	0.042	0.051
2003 Ford F150	0.021	0.016	0.016	0.017
2003 Ford Taurus	0.094	0.078	0.079	0.121
2003 Nissan Altima	0.048	0.042	0.051	0.064
2003 Toyota Camry	0.180	0.154	0.164	0.163
2004 VW Golf GTI	0.034	0.042	0.028	0.047
2007 Buick Lucerne	0.071	0.058	0.056	0.059
2007 Chevrolet Silverado	0.046	0.039	0.035	0.044
2007 Chrysler T&C	0.017	0.017	0.034	0.027
2007 Ford F150	0.031	0.008	0.012	0.018
2007 Honda Accord	0.010	0.009	0.009	0.014
2007 Toyota Camry	0.021	0.037	0.032	0.028
Average	0.062	0.054	0.056	0.060

Attachment 4

Vehicles in DOE Catalyst Study

Vehicle Characteristics				
Year	Make	Model	Engine	Emission Standard
2000	Chevrolet	Silverado	5.3L V8	Pre-Tier2
2000	Ford	Focus	2.0L I4	Pre-Tier2
2000	Honda	Accord	2.3L I4	Pre-Tier2
2002	Dodge	Durango	4.7L V8	Pre-Tier2
2002	Nissan	Frontier	2.4L I4	Pre-Tier2
2003	Chevrolet	Cavalier	2.2L I4	Pre-Tier2
2003	Ford	Taurus	3.0L V6	Tier 2, Bin 8
2003	Toyota	Camry	2.4L I4	Pre-Tier2
2005	Ford	F150	5.4L V8	Tier 2, Bin 8
2005	Toyota	Tundra	4.0L V6	Tier 2, Bin 5
2006	Chevrolet	Cobalt	2.2L I4	Tier 2, Bin 5
2006	Chevrolet	Impala	3.9L V6	Tier 2, Bin 5
2006	Chevrolet	Silverado	5.3L V8	Tier 2, Bin 8
2006	Ford	F150	5.4L V8	Tier 2, Bin 8
2006	Nissan	Quest	3.5L V6	Tier 2, Bin 5
2007	Dodge	Caliber	2.0L I4	Tier 2, Bin 5
2007	Dodge	Caravan	3.3L V6	Tier 2, Bin 5
2007	Honda	Accord	2.4L I4	Tier 2, Bin 5
2008	Ford	Taurus	3.5L V6	Tier 2, Bin 5
2008	Nissan	Altima	2.5L I4	Tier 2, Bin 5
2009	Ford	Explorer	4.0L V6	Tier 2, Bin 4
2009	Ford	Focus	2.0L I4	Tier 2, Bin 4
2009	Honda	Civic	1.8L I4	Tier 2, Bin 5
2009	Honda	Odyssey	3.5L V6	Tier 2, Bin 5
2009	Jeep	Liberty	3.7L V6	Tier 2, Bin 5
2009	Saturn	Outlook	3.6L V6	Tier 2, Bin 5
2009	Toyota	Camry	2.4L I4	Tier 2, Bin 5
2009	Toytoa	Corolla	1.8L I4	Tier 2, Bin 5