FINAL REPORT

Ethanol Research

Alternative Fuels & Life-Cycle Engineering Program

November 29, 2006 to November 28, 2011

Prepared for:

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Executive Summary

This report presents the results of the successful ethanol fuel demonstration program conducted from September 2007 to September 2010. This project was a part of the U.S. Department of Transportation (DOT) Alternative Fuels and Life Cycle Engineering Program conducted by the Center for Integrated Manufacturing Studies (CIMS) at the Rochester Institute of Technology (RIT) under award number DT0S59-07-G-00049.

The initial literature search identified two primary methods in which ethanol is used as a transportation fuel: first as a petroleum extender with a small percentage added to gasoline, and second as a primary fuel (E85) to be used in flex fueled vehicles. Research was identified to cover both of these ethanol fuel uses. In the summer of 2007, RIT received a request from the DOT to perform a special, “high interest” evaluation of a mid-level blend (E20) ethanol fuel in older vehicles that were not designed for ethanol fuel mixtures. Mid-level blend fuel was not an approved fuel and would require a waiver from the U. S. Environmental Protection Agency (EPA) to be used by the general public. This approval process required data to enable the EPA can make informed decisions.

In response to the DOT request for E20 research, RIT expanded its ongoing E85 ethanol study and partnership with Monroe County to implement a plan to test E20 ethanol fuel within the County fleet vehicles. Vehicles were chosen that had significant accumulated miles (between 30,000 and 120,000 miles) and model years ranging from 1998-2004. This would ensure a representative test population that already had significant gasoline use but could potentially still be in operation if mid-level blends were implemented. After preliminary results were mainly positive, the test fleet was expanded to include nearly 400 gasoline vehicles in the Monroe County.

The E20 investigation focused on issues requiring evaluation to receive the EPA waiver, such as: vehicle emissions, drivability, and engine and fuel system durability and reliability. This research was designed to leverage off the well-documented use and historical record of the Monroe County vehicle fleet running on gasoline. County fleet vehicles consist mainly of medium- and light-duty trucks, and passenger vehicles. At the time of this writing, the research fleet includes over 400 conventional gasoline engine vehicles running on E20, and 103 flex fueled vehicles (FFV) running on E85 or a combination of E20 and E85 making the County fleet the largest known ethanol study fleet in the country. The E20 vehicle fleet in particular has used more than 350k gallons of E20 and driven more than 5 million miles on E20 without any adverse effects on the vehicles. CIMS accomplished all the program tasks and objectives established at the beginning of the DOT program and results of this program were used to support the mid-level blends waiver approval. We consider this a successful vehicle demonstration program and we look forward to engaging in future ethanol projects and vehicle demonstration programs.

This report begins with a brief discussion on the benefits and challenges with using ethanol in fuel. This is followed by detailed emissions, driveability, fuel economy, and durability data collected on the Monroe County fleet vehicles. These results were also used to support the technology readiness evaluation for ethanol fuels. The following are highlights:

Vehicle Tailpipe Emissions

Beginning in February 2008, ten (10) older gasoline vehicles owned and operated by Monroe County, were evaluated by the RIT while running on E20 fuel. The purpose of our emissions testing was to look for trends within the vehicles and fuels that may expose a significant impact on the entire fleet. Criteria pollutant tailpipe emissions from running E20 versus gasoline were tested using the FTP-75 Federal Test Procedure in an independent vehicle emissions laboratory. These tests were repeated after one year of operation to investigate any degradation that may have occurred with use of E20. Vehicles experienced a net reduction in hydrocarbons (non-methane organic gases and non-methane hydrocarbons) and carbon monoxide (CO) while using E20 over emissions from conventional gasoline and there was statistical parody in methane (CH_4) and oxides of nitrogen (NO_x) emissions on E20 with conventional gasoline. Year over year results showed some degradation in emissions for vehicle running on E20 and on gasoline; however, all emissions met EPA requirements for all states.

Vehicle Fuel Economy

Vehicle fuel economy (miles per gallon) is theoretically reduced when ethanol is blended with gasoline due to the lower energy content of ethanol. Several factors outside of fuel energy content however can significantly affect fuel economy such as weather, driver behavior, fuel variation, and vehicle condition and maintenance. This paper contains results for the vehicle fuel economy and operating cost comparing the performance of E85 in flex fueled vehicles and E20 in conventional gasoline vehicles. The resulting fuel economy was compared to the performance of conventional gasoline run in the same vehicle. The fuel economy was determined experimentally through measuring the carbon exhaust emissions while running the FTP-75 Federal Test Procedure and calculating the fuel economy based on the carbon content of the fuel, and practically based on two years of on-road operations of 74 vehicles using over 110,000 gallons of fuel. The fuel economy was shown to decrease with ethanol content; however, the reduction was less than expected based on the fuel energy content. Additionally, the national E85 ethanol fuel prices appear to be closely correlated to the price of gasoline keeping the consumer E85 operating cost at breakeven to a slight premium after prices are adjusted for vehicle fuel economy.

Petroleum Savings

A major goal of using alternative fuels is to reduce the amount of gasoline (petroleum) used in transportation, thereby reducing the nation's dependence on foreign oil. For the County E20 use, the gasoline content in the fuel was 80 percent and the fleet fuel economy was reduced by 5.9 percent. The gasoline consumption was therefore reduced by 15 percent due to the use of E20 over gasoline. Monroe County used 250,000 gallons of E20 per year thereby saving 35,250 gallons of gasoline per year by using E20. Higher gasoline use reductions per vehicle mile were achieved by using E85. For the County E85 use, the gasoline content in the fuel was 24.2 percent and the fleet fuel economy was reduced by 14 percent. The County gasoline consumption was therefore reduced by 71.9 percent. The County used 55,000 gallons of E85 per year thereby saving 33,990 gallons of gasoline per year by using E85.

Vehicle Drivability

Monroe County test vehicles were operated by Monroe County employees and driven on public roads in an uncontrolled manor based on the fleet mission. Prior to the study, each vehicle had spent numerous years running on gasoline, operated by a known set of drivers. These drivers were then educated on the ethanol project, and asked to participate in an evaluation of their vehicles running on E20. Subjective data was collected on each vehicle through review cards filled out by the operator at each refueling. Additionally, each operator filled out a drivability and performance survey during a mid-program review. On average, the drivers felt that the vehicles performed equal to or better on E20 as the same vehicle did running on gasoline.

Vehicle Reliability

As a policy, Monroe County maintains their vehicles strictly according to the manufacturer recommendations for preventive maintenance. The impact of E20 on vehicle reliability was assessed by looking at scheduled and unscheduled maintenance events. Monroe County uses a database to track all vehicle maintenance events and part and labor cost. RIT was granted access to all vehicle maintenance records from vehicle purchase through the present. There was no measureable difference in maintenance between the same set of vehicles running on gasoline versus E20 fuel.

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Introduction

Congress directed the U.S. Environmental Protection Agency (EPA) in the Energy Policy Act of 2005 (Public Law 109-58) to design a program that requires the blending of renewable fuels into the nation's motor-vehicle fuel supply, known as the Renewable Fuel Standard. The Renewable Fuel Standard program increases the volume of renewable fuel required to be blended into gasoline from nine billion gallons in 2008 to 36 billion gallons by 2022.

Renewable fuels are blended into gasoline primarily in two methods. First, a small volume of ethanol is blended into gasoline to be used in conventional vehicles. Section 211(f)(1) of the Clean Air Act (CAA) however, prohibits introducing into commerce, or increasing the concentration in use of, any fuel or fuel additive which is not substantially similar to any fuel or fuel additive utilized for emissions certification of any model year 1975 or later, unless a waiver is obtained from the EPA. The fuel must possess, at the time of manufacture, all of the physical and chemical characteristics of an unleaded gasoline as specified by ASTM D4814. This standard states that a fuel which contains an alcohol, such as ethanol, must contain no more than 2.7 mass percent oxygen. Additionally, a waiver has been approved for "gasohol" or fuel containing up to 10 percent anhydrous ethanol. This fuel is known commercially as "E10" and is now available throughout most of the U.S.

Mid-level ethanol blends (E15/E20) have high oxygen content, and therefore fail to meet the EPA's "substantially similar" criteria. Adoption of mid-level blend ethanol therefore requires a waiver under the CAA section 211(f)(4). The EPA approved a limited waiver for E15 in January 2011 for some light duty vehicles, model year 2001 and later.

The second method to increase renewable fuel use is through fuel ethanol, typically referred to as E85, which contains a mixture of up to 85 percent denatured ethanol and gasoline by volume. E85 however requires a vehicle designed specifically to run on high concentrations of ethanol, referred to as a "Flex Fuel" Vehicles (FFV). Flex fuel vehicles can be fueled with conventional gasoline, E85, or any combination of the two.

The Rochester Institute of Technology (RIT) partnered with the local municipality, Monroe County of New York, to examine the impact of ethanol fuels on the fuel economy of a large, real world fleet. The Monroe County Department of Environmental Services (DES) maintains and repairs over 840 vehicles and equipment assigned to county departments (e.g., Parks, Transportation, Public Safety, Health, Greater Rochester International Airport, etc) with a staff of 10 automotive technicians. The fleet includes 302 light, 382 medium, and 159 heavy units of various makes and models. At the time of this writing, over 400 vehicles are conventional gasoline engines running on E20; 103 vehicles are FFV and run on E85 or a combination of E20 and E85 making the County fleet the largest known ethanol study fleet in the country.

As a policy, Monroe County maintains their vehicles strictly according to the manufacturer recommendations for preventive maintenance. The County uses a multi-site fleet management system to track all fueling [PetroVend] and vehicle maintenance events and part and labor cost [FleetMax]. RIT was granted access to all required vehicle records.

Monroe County vehicles are operated exclusively by County employees and driven on public roads in an uncontrolled manner based on the fleet mission. The vehicles operate in all weather extremes throughout the year and experience a mixture of city, suburban and rural driving. Vehicles selected for this study represent typical county fleet vehicles and consist mainly of domestic medium- and light-duty trucks, and passenger vehicles. None are used outside of the county, assuring that they always fueled at the designated station.

Monroe County is ideally located to test the performance of ethanol fuels as general vehicle performance characteristics are known to vary with changes in weather conditions such as cold start issues in the winter and vapor lock in the summer. Monroe County is located on the south shore of Lake Ontario in upstate New York and experiences seasonal weather changes. County temperatures range from a summer high in the mid-90s Fahrenheit (35°C) to a winter low of slightly below zero Fahrenheit (-20°C), and it is approximately 500 feet (152 m) above sea level. Most winters can produce a total snowfall greater than 100 inches (2.5m), and the County can experience yearly rainfall of approximately 30 inches (0.8m).

No E85 was being sold commercially in the County at the start of this project in 2006 and therefore the County had the desire to participate in the public investigation of ethanol fuels. The County officially opened the new Green Fuel Station in Rochester NY in August of 2008. The new facility includes a hydrogen fuel station, several grades of ethanol fuel including E85 and E20, B-20 biodiesel, and compressed natural gas (CNG). The first delivery of pre-blended, or rack-blended, E20 was received from Griffith Energy on 12/15/08. This delivery initiated the fuel economy study.

The delivery and testing of rack-blended E20 fuel in conventional vehicles was covered by the EPA research waiver for the program duration. Written confirmation from the EPA was requested by the fuel supplier prior to providing rack-blended E20 fuel. Specifically:

> *"Under 40 CFR Part 79, which governs registration of fuel and fuel additives, fuel that is in a research, development or test status is exempt from registration."*[1]

[1] Email correspondence with Anne-Marie Pastorkovich OAR/OTAQ/TRPD/FPSG, dated 9/9/08

Ethanol Background

In the Energy Information Administration's 2006 International Energy Outlook reference case, it is projected that world oil demand will grow from 80 million barrels per day in 2003 to 98 million barrels per day in 2015 and 118 million barrels by 2030[2]. Given our current supply of oil, this increased demand will place a severe strain on our ability to meet world energy needs. Currently, the world's Proved Reserves of oil are estimated at 1,292.5 billion barrels[3], meaning that if we average 98 million barrels per day those reserves will be depleted in 36 years. Even when reserve growth and undiscovered oil resources are included, the estimated world oil supply does not exceed 2,961.6 billion barrels, all of which could be depleted by the end of this century if conservation or alternate energy systems are not implemented.

In addition, there is concern regarding national energy security. As of March 2007, U.S. motor gasoline consumption was 9,159,000 barrels per day.[4] (140.4 billion gallons of gas per year) Gasoline is a major end product of petroleum. According to the U.S. Department of Energy, the United States consumed 20.75 million barrels of petroleum per day[5], or about one-quarter of total world production, in 2005. Over 60% of this was imported from foreign sources. This reliance on imported oil makes the U.S. vulnerable to oil supply disruptions, price fluctuations and global energy disputes. Most experts now believe that the U.S. needs to make increased domestic energy production a priority to maintain future energy and economic stability.

Given these supply and security challenges, U.S. energy policy is dependent on developing and implementing plentiful and affordable alternative energy technologies. Liquid biofuels such as ethanol, which are compatible with current internal combustion engine technology, offer the highest potential for rapid introduction and replacement of fossil fuels on a large scale.

Ethyl alcohol, or ethanol, (C_2H_5OH) is a colorless liquid with a mild characteristic odor, and is miscible in all proportions with water. Ethanol vapor forms an explosive mixture with air and can be used in some internal combustion engines under compression as fuel.[6] Ethanol can be produced from almost any agricultural raw material which includes carbohydrate content in the form of sugars or starches that can easily be converted to sugars. Yeast enzymes are added to commence natural fermentation, the products of which are ethyl alcohol and carbon dioxide.

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[2] USDOE, 2006, "International Energy Outlook-2006", U. S. Department of Energy, Energy Information Administration, DOE/EIA-0484(06), pg 25

[3] USDOE, 2006, "International Energy Outlook-2006", U. S. Department of Energy, Energy Information Administration, DOE/EIA-0484(06), pg 29

[4] http://www.eia.doe.gov/neic/quickfacts/quickoil.html

5 USDOE, 2006, "Annual Energy Outlook 2007 with Projections to 2030", U.S Department of Energy, Energy Information Administration, DOE/EIA-0383(2007), pg 14

[6] Van Nostrand's Scientific Encyclopedia, Fifth Edition, Van Nostrand Reinhold Company, 1976

In the United States, ethanol is currently produced primarily from the starch in corn kernels. New research is also advancing ethanol production utilizing cellulosic feed stocks derived from the fibrous, woody and generally inedible portions of plant matter (biomass), including switchgrass, straw, corn stover, and wood chips. This research focuses on cost effectively separating and breaking down the different polymers in the selected biomass. While efforts in this area are gaining results, the process is still primarily in the development stages.

The chemical composition of ethanol is the same no matter the feedstock; therefore, the feedstock does not directly affect the transportation industry. However feedstock choices affect the total amount of ethanol that may be available as a transportation fuel, and also the life-cycle environmental impacts associated with fuel use.

Vehicle Emissions

The Monroe County Department of Environmental Services (DES) maintains and repairs over 840 vehicles and equipment assigned to county departments (e.g., Parks, Transportation, Public Safety, Health, Greater Rochester International Airport, etc) with a staff of ten automotive technicians. Ten (10) older vehicles were selected for emissions testing. Vehicles were chosen that were a cross-section of the County fleet, had significant mileage accumulation on gasoline, had never used fuel that contained ethanol, and model years ranging from 1998-2004. (See Table 1) This would ensure a representative test population that already had significant gasoline use but could potentially still be in operation if mid-level blends were implemented. After one year of operation and preliminary positive results, the test fleet was expanded. At the time of this writing, over 400 conventional gasoline vehicles are running on E20.

As a policy, Monroe County maintains their vehicles strictly according to the manufacturer recommendations for preventive maintenance. The County uses a multi-site fleet management system to track all fueling (OPW Fuel Management Systems, PetroVend) and vehicle maintenance events and part and labor cost (FleetMax™). RIT was granted access to all required vehicle records. Additionally, RIT had installed Networkcar's® Networkfleet™ wireless vehicle management system on all ten evaluation vehicles. These systems transmit both vehicle location and performance information on a regular basis and enables fleet managers to easily locate vehicles in real-time and view specific vehicle data such as current location, mileage and speed. All Diagnostic Trouble Codes (DTC) are also transmitted. This data enabled RIT and the County to immediately react to any maintenance issues throughout the evaluation duration.

Vehicle Fueling and Infrastructure

Monroe County officially opened the new Green Fuel Station in Rochester, NY in August of 2008. The facility includes a hydrogen fuel station, several grades of ethanol fuel including E85 and E20,

Unit ID	Yr	Model	Date of 1st Emissions Test (gas)	Odometer at Emissions test (gas)	Date of 1st Emissions Test (E20)	Total miles driven on E20	Date of back to back test	Total miles driven on E20
3562	1998	F150	12/3/07	73860	8/19/08	6423	11/4/2009	20575
3675	2000	Impala	11/6/07	83030	8/26/08	6936	9/22/2009	12710
4029	2001	F250	11/11/07	54499	7/30/08	3028	8/26/2009	8404
4030	2001	F250	11/6/07	107611	8/06/08	8804	11/4/2009	23175
4066	2001	Silverado	11/27/07	119776	8/19/08	11445	9/22/2009	27806
4075	2001	Blazer	11/27/07	48787	8/12/08	3584	10/6/2009	10930
4126	2002	G3500	11/11/07	82794	8/12/08	4876	10/20/2009	15195
4137	2002	F250	11/11/07	120818	7/30/08	2457	8/26/2009	9976
4140	2002	Sierra1500	11/27/07	51123	8/06/08	4181	10/22/2009	15323
4230	2004	F250	11/1/07	29738	8/12/08	6514	10/6/2009	24099
					Total	**58248**	**Total**	**168193**

Table 1: Test Vehicle ID and Test Mileage

B-20 biodiesel, and compressed natural gas (CNG). The first delivery of pre-blended, or rack-blended, E20 was received from Griffith Energy on 12/15/08. This delivery initiated the use of E20 fuel in most of Monroe County's conventional gasoline vehicles.

Since the major objective of the research program was not certification, but to evaluate the impact of alternative fuels on transportation in the U.S., ordinary commercial road fuels were used throughout the program in lieu of special test fuels. Both the vehicles and fuels would therefore be representative of normal consumers and fleet users. The Country received rack-blended E20 fuel shipments as needed of between 2,000 and 5,000 gallons (7,570-18,930 liters) every 3-5 days, consuming nearly 250,000 gallons (946,000 liters) of E20 per year. In keeping with the "real-world" evaluation, no special provisions were made to control the gasoline component of the E20 outside of typical New York State contract and quality assurance requirements and therefore the gasoline component was subject to normal market and seasonal composition fluctuations. An E20 sample was pulled from every shipment and measured for ethanol content following the guidelines in SAE 912421. The average ethanol content of the rack-blended E20 fuel over one year was 19 percent.

Exclusively for this emissions evaluation, Griffith Energy provided the base conventional gasoline (E0) that they used to blend to make E20 at the time of the evaluation. The conventional gasoline was stored offsite from the County Green Fuel Station, and shipped to Delphi when required. This conventional gasoline was used in the emissions testing of E0, and E20 made using this E0 was used in the emissions testing of E20.

As with most real-world evaluations, there are challenges that arise outside of process control. New York State changed fuel contractors towards the end of this evaluation meaning that the County fuel would no longer be supplied by Griffith Energy and would now be supplied by NOCO Energy Corp. Fuel provided by NOCO continued to meet the same contractual specifications for rack blended E20; however, the final two vehicles tested (3562, and 4030) were fueled with NOCO E20, and used conventional gasoline provided by Delphi as opposed to the first eight vehicles which used fuel from Griffith Energy.

Experimental Setup

Emissions Testing Setup

The Delphi Powertrain Systems Technical Center in Rochester, NY, was contracted to provide detailed emissions data for this project. The Technical Center is a 350,000 sq-ft facility dedicated to the design, development, and testing of air/fuel systems, emission control, valve train and fuel cell systems, and components for worldwide application. The facility contains state-of-the-art testing equipment, including specialized vehicle and engine emissions equipment.

The Monroe County vehicles were tested on a 100 HP (75 KW) Burke Porter twin roll chassis dynamometer. Tailpipe emissions were analyzed on a Horiba OPE series analyzer.

The Delphi Horiba emissions tester was not capable of measuring ethanol emissions; therefore, NREL provided an Innova Photoacoustic Multi-gas Monitor.

Ethanol is a dominant factor in the NMOG calculation – generally an order of magnitude above combined aldehydes. For E20 fueling, ethanol expected to be about 20% of total NMOG, combined aldehydes expected to be about 4% of total NMOG. Aldehydes were not measured.

Although sampling of aldehydes would provide a more complete inventory of tailpipe emissions, it is not considered necessary for the current test series. Adequate information exists from other tests in the mid-level blend test program.

FTP-75 Driving Cycle

The FTP-75 (Federal Test Procedure) has been used for emissions testing of light duty vehicles for many years. The drive cycle consists of a cold start phase (505 seconds), a transient phase (864 seconds), and a hot start phase (505 seconds). The hot start phase starts after the engine is stopped for 10 minutes. The emissions from each phase are collected in separate bags, analyzed and expressed in g/mile. The total vehicle emissions are weighted by phase with the weighting factors as: 0.43 for the cold start, 1.0 for the transient phase, and 0.57 for the hot start phase.

Test Sequence

Vehicles were delivered to the Delphi facility having been fueled with E20 and having been driven exclusively on E20 since the previous emissions evaluation. The vehicles emissions were then measured by running tests on both E20 and E0 back-to-back to assure that differences in emissions performance were attributed to the fuel only. The following protocol was followed to condition each vehicle on the fuel being tested.

Drivetrain and Exhaust Inspection

Vehicle Preconditioning:

- 5 minute @ 50 mph
- US06
- 24 Hour Soak @ 70 °F
- 5 minute @ 50 mph
- LA4 schedule
- FTP75 schedule + 2 minute idle (no emissions)
- 24 Hour Soak @ 70 °F

Emissions Test:

- FTP75 schedule + 2 minute idle
- 24 Hour Soak @ 70 °F
- Repeat Emissions test 2x

Fuel Change / Adaptation:

- Drain and ½ refill with E0 fuel
- 5 minute @ 50 mph
- US06
- Drain and ½ refill with E0 fuel
- 24 Hour Soak @ 70 °F

Vehicle Preconditioning:

- 5 minute @ 50 mph
- LA4 schedule
- FTP75 schedule + 2 minute idle (no emissions)
- 24 Hour Soak @ 70 °F

Emissions Test:

- FTP75 schedule + 2 minute idle
- 24 Hour Soak @ 70 °F
- Repeat Emissions test 2x

The FTP weighted vehicle emissions were averaged from three separate FTP75 runs for each fuel.

Figure 1: Monroe County Vehicle 4075 in the Delphi Emissions Lab

Tailpipe Emissions

E20 fuel has not been approved by the EPA for use in conventional vehicles, however, as shown in Figure 2, it is already available in some areas of the U.S. for use in Flex Fuel Vehicles. To gain a waiver, E20 tailpipe emissions from conventional vehicles must meet the gasoline emissions requirements defined in the vehicle emissions standards. Many people believe that ethanol may be a cleaner burning fuel and may be the next step in further decreasing tailpipe emissions. However, there is considerable debate regarding how "clean" ethanol actually is and further testing is required to better understand the fuel's emission potential compared to that of gasoline. This report hopes to contribute to the overall scholarship on the subject of ethanol fuel emissions. The following sections present a review of the current data set, data from a previous emissions report which studied the same vehicles, and an analysis of the difference between the two sets of data.

Figure 2: E20 is available at some retail stations in the U.S. (example from Oshkosh WI, July 2009).

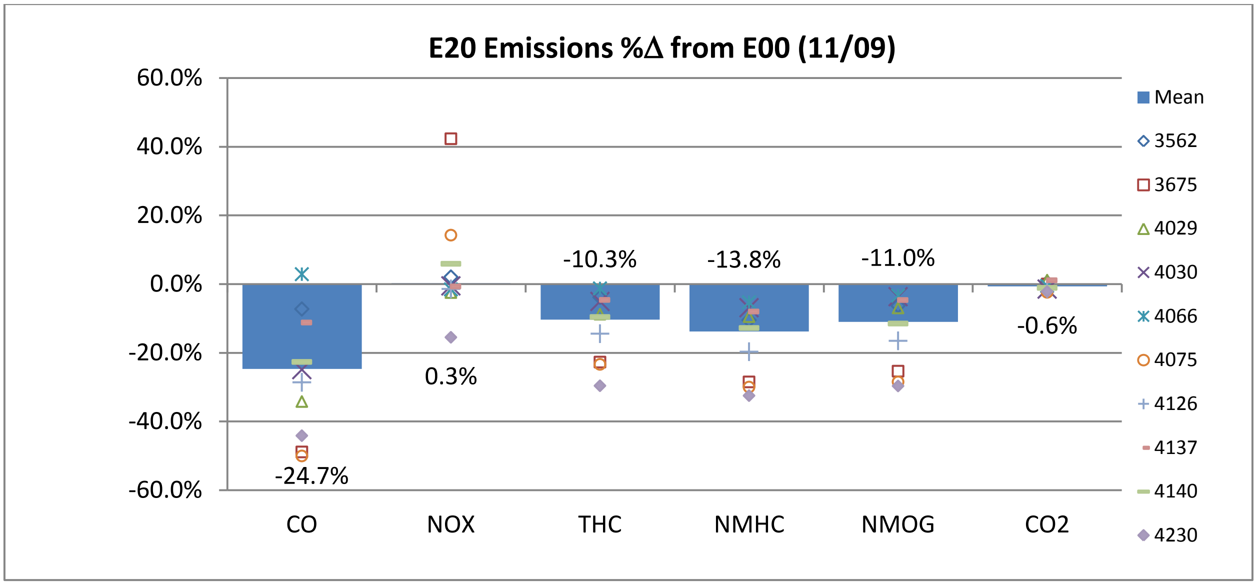
Back to Back Results

The vehicle emissions while running on E20 were compared to the same vehicle emissions while running on E0. The E20 fuel was made from the E0 road fuel; therefore, the difference in emissions can be attributed to the ethanol content. The emissions were also taken back-to-back to minimize the vehicle degradation between fuels.

The test vehicles running on E20 showed a statistically significant reduction in carbon monoxide emissions (CO reduction of 24.7 percent), in non-methane hydrocarbons (NMHC reduction of 13.8 percent), and, factoring in the ethanol measurements, non-methane organic gases (NMOG reduction of 11.0 percent). All ten vehicles demonstrated a reduction in NMHC and NMOG, and nine out of ten vehicles demonstrating a reduction in CO. Summary data is in Figure 3 below with individual vehicle data in appendix A.

The difference between the vehicle tailpipe emissions running on gasoline versus running on E20 was statistically insignificant for both oxides of nitrogen (NOx increase of 0.3 percent) and carbon dioxide (CO2 decrease of 0.6 percent). The vehicle distribution was split with half the vehicles showing an increase in NOx and half showing a decrease in NOx. The two vehicles that had the highest percent increase in NOx (3675, and 4075) also had the lowest nominal values.

Figure 3: Emissions Differences between E20 and Conventional Gasoline



Previous Results

For comparative purposes, data from the previous emissions evaluation on these same ten vehicles is summarized in Figure 4 below with detailed data in appendix A. Details of this study can be found in Hilton and Duddy (2009)[7]. Test methods and data collection between the two events was essentially the same except for the alcohol measurements taken in only the follow-up event.

The previous evaluation did not run back-to-back as detailed in the report. Conventional gasoline was tested first, and then a significant distance (mileage accumulation is documented in Table 1) was run on E20 prior to the E20 emissions evaluation. Additionally, the test program was in its infancy and all E20 fuel was splash blended by hand, not rack blended. Each batch of fuel was tested using the SAE method[8] to assure that it was 20 percent ethanol.

Previously, these vehicles running on E20 also showed a statistically significant reduction in carbon monoxide emissions (CO reduction of 23.2 percent), and in total hydrocarbons (THC reduction of 13.7 percent). NMOG is not reported since ethanol emissions were not previously measured. Nine out of ten vehicles demonstrated a reduction in CO and THC.

The difference in tailpipe emissions between gasoline and E20 was statistically insignificant for both oxides of nitrogen (NOx decrease of 2.4 percent) and carbon dioxide (CO2 decrease of 3.6

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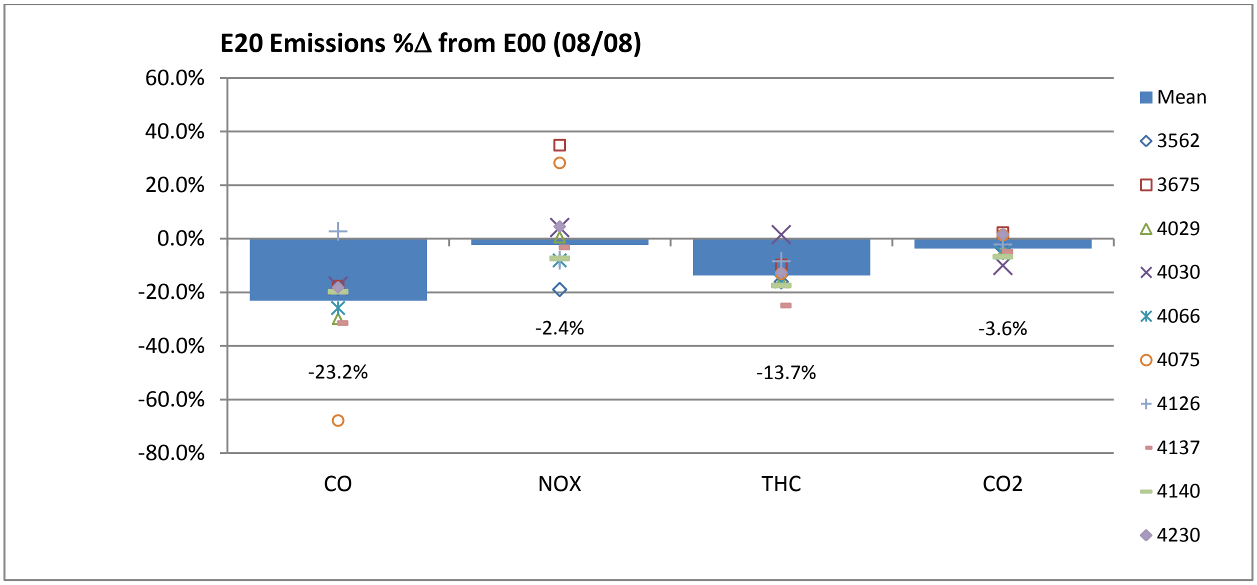
[7] Hilton, B. and Duddy, B. *The effect of E20 ethanol fuel on vehicle emissions.* Proc. IMechE, Part D: J. Automobile Engineering, 2009, 223 (D12), -. DOI10.1243/09544070JAUTO1188

[8] Scott W. Jorgensen, et al, *A Simple Method to Determine the Methanol Content of Methanol Fuels.* SAE Technical Paper 912421, from Alternative Liquid Fuels in Transportation, October 1991.

percent). The vehicle distribution was split with half the vehicles showing an increase in NOx and half showing a decrease in NOx.

These results are very similar to the current evaluation.

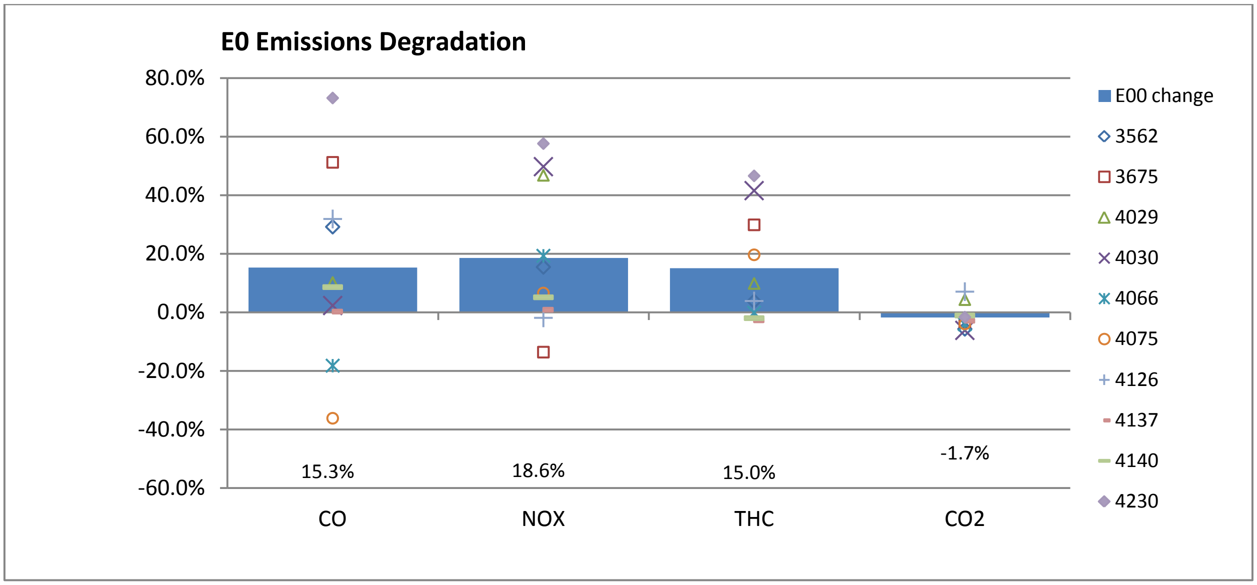
Figure 4: Previous Emissions Results.

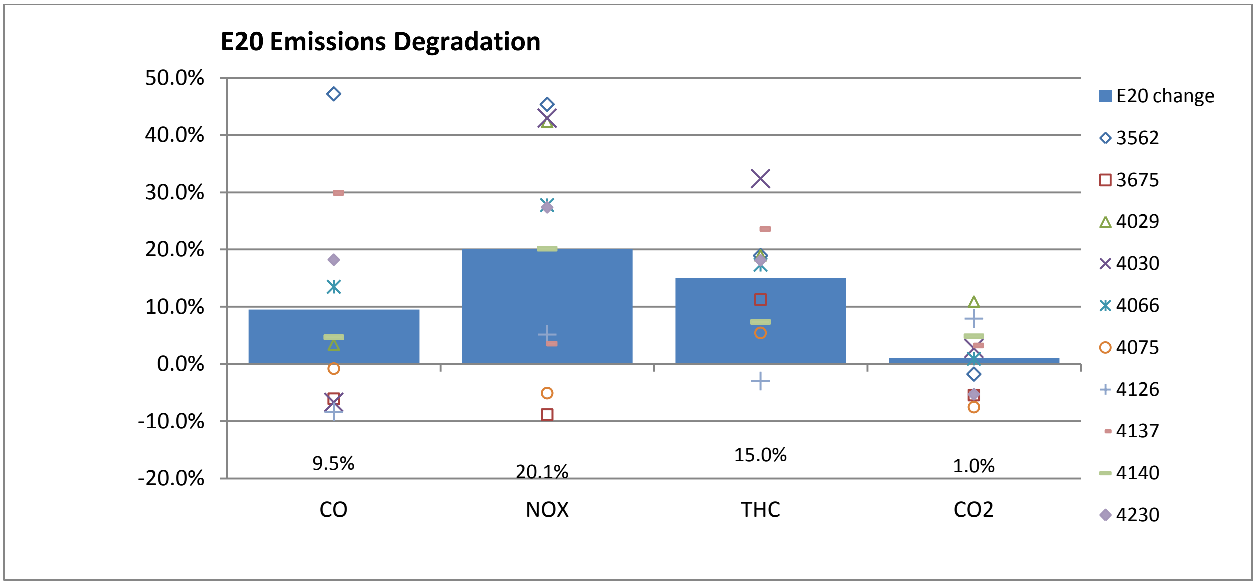


Emissions Degradation

The other concern investigated, besides the absolute emission levels, was the potential for degradation of the vehicle emission control system over time. The EPA currently requires vehicle manufacturers to certify the emissions compliance of their vehicles at two points in their life-cycle: less than 6250 miles and 50,000 miles (40 CFR, Chapter 1, §86.090-26). Against that background, the vehicles running on E20 should still be able to meet EPA standards (without modification) at their 50K mile point in order for the fuel to be accepted for consumer use. In the case of the ten study vehicles, the emissions from the first run were compared to the emissions from the second run for each fuel separately. (figures 5 and 6) This data shows that there was some degradation between the first and second testing periods, but all the vehicle emissions were still below the EPA threshold on both fuels and all vehicles had over 50K miles on them, and in some cases, well over 100K miles.

Figures 5 and 6: Degradation in E0 and E20 Tailpipe Emissions over Time.





Conclusions

The emissions testing accomplished under this long-term program as shown that E20 fuel has real potential to be accepted as a motor fuel in conventional vehicles and may result in significant reduction in criteria pollutants and improved air quality. In particular, the major reductions in carbon monoxide and non-methane hydrocarbons by using E20 are very encouraging. The overall results of this E20 test and evaluation program have shown no technical drawbacks to its use in conventional light duty vehicles. However, further work must continue to completely demonstrate the effectiveness and suitability of the fuel not only in light duty vehicles, but other spark-ignited gasoline applications.

Vehicle Fuel Economy

U.S. automobile owners are now confronted with an array of fuel choices for their vehicle – unleaded, E10 and E85 ethanol blends, and soon-to-be E15 or even E20. With little insight into the vehicle performance using these fuels, the consumer is handicapped when trying to identify the "best value" fuel for their application. In this case, best value is defined as cost per mile.

This section focuses on the fuel economy and cost tradeoffs for various blends of ethanol fuels. Fuel economy is defined as the amount of fuel required to move a vehicle over a given distance. For this evaluation, fuel economy is expressed as the distance travelled per unit of fuel used, or miles per gallon (mpg). The fuel economy for both E20 and E85 was determined experimentally based on measured exhaust emissions while running the FTP-75 Federal Test Procedure, and practically based on extensive on-road operations. These values were compared to the theoretical fuel economy based on the fuel energy content.

Theoretical Vehicle Fuel Economy

Ethanol contains less energy per volume (BTU/gal) than gasoline as shown in Table 1; therefore, vehicle fuel economy will theoretically decrease when ethanol is blended with gasoline. More fuel is required to provide the same power, thereby increasing fuel use per mile assuming the vehicle controller is able to maintain stoichiometric combustion conditions.

Table 1: Fuel Energy Content [USDOE]

	Energy Content (BTU / gal)
Energy of gasoline	116,090
Energy of ethanol (E100)	76,330
E85 Ethanol Fuel Energy	82,294
Fuel Economy change of E85 w.r.t. gasoline (%)	-29.1%
E20 Energy	108,138
Fuel economy change of E20 w.r.t. gasoline (%)	-6.8%

Note that E85 is not always 85 percent ethanol, as the actual ethanol content is adjusted with the seasons. Additional hydrocarbons are added to increase the vapor pressure to improve starting and driveability in colder climates. This decreases the ethanol content, and therefore increases the energy content of winter blend fuel. ASTM D5798 Standard Specification for fuel ethanol (Ed75-Ed85) for automotive spark-ignition engines is used to set the requirements for E85 fuel. It has three classes of fuel: class 1 has a minimum of 79 percent ethanol, class 2 has a minimum of 74 percent ethanol, and class 3 has a minimum of 70 percent ethanol. Extracted from ASTM D5798 table 2, "Seasonal and geographical volatility specifications for fuel ethanol," the following table 2 applies to fuel sold in Monroe County, NY.

Table 2: ASTM Seasonal E85 Fuel Classification for Upstate NY

Month	E85 Class	Month	E85 Class
January	3	July	1
February	3	August	1 / 2
March	3	September	2
April	3 / 2	October	2 / 3
May	2	November	3
June	2 / 1	December	3

Using the stated ASTM minimum ethanol values for the various fuel classes, the average minimum ethanol content for E85 fuel in upstate New York is 75.8 percent. This yields an average energy reduction of 26.0 percent for Monroe County assuming the gasoline energy is consistent with the seasons. The average energy reduction for E20 is 6.8 percent.

Experimental Fuel Economy

All passenger vehicles sold in the United States must undergo fuel economy certification by the U.S Environmental Protection Agency (EPA) for each model year. The EPA fuel economy estimates are based on laboratory testing performed by the auto manufacturers and EPA and are calculated by precisely measuring the carbon compounds expelled in the vehicle exhaust during the emissions tests, knowing the amount of carbon in the fuel, and using a carbon balance equation. Vehicles are driven over identical driving patterns by professional drivers in controlled laboratory conditions on a dynamometer. A description of the test conditions can be found on the EPA's website.[9]

All flex fuel vehicles sold in the U.S. must undergo fuel economy testing for both gasoline and E85, and therefore, experimentally derived fuel economy numbers for E85 and gasoline in flex fuel vehicles are widely available. Roberts[10] analyzed the fuel economy tests performed by the EPA for the 2007 model year. The results were an average 26.6 percent reduction in fuel economy from conventional gasoline to E85 for 76 total vehicle models tested.

Experimental fuel economy results using E20 in conventional vehicles could not be found in the public record and therefore were generated. The Delphi Powertrain Systems Technical Center in Rochester, NY, was commissioned to provide detailed emissions data on conventional vehicles running on both gasoline and E20. The Technical Center is a 350,000 sq-ft facility dedicated to the design, development, and testing of air/fuel systems, emission control, valve train and fuel cell systems, and components for worldwide application. The facility contains state-of-the-art testing equipment including specialized vehicle and engine emissions equipment.

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[9] U.S. Environmental Protection Agency, EPA's Fuel Economy Programs, EPA420-F-07-066, October 2007, http://www.epa.gov/fueleconomy/420f07066.htm

[10] Roberts, M.C., E85 and fuel efficiency: An empirical analysis of 2007 EPA test data, Energy Policy 36, (2008), pg 1233-1235

Ten (10) representative County vehicles were tested in the Delphi lab designated as VEL2, which contains a 100 HP (75 kW) Burke Porter twin roll chassis dynamometer that can handle speed ranges of 0 to 80 MPH with road, speed and torque load modes. Bag emissions data was collected and analyzed on a Horiba OPE series analyzer.

The FTP-75 (Federal Test Procedure) was used to collect emissions data. The drive cycle consists of a cold start phase (505 seconds), a transient phase (864 seconds), and a hot start phase (505 seconds). The hot start phase starts after the engine is stopped for 10 minutes. The basic drive cycle parameters are 11.04 miles traveled, 1874 total seconds, with a 21.2 mph average speed. The emissions from each phase were collected in separate bags, analyzed and expressed in g/mile.

The emissions were evaluated on conventional vehicle running on both E20 and conventional gasoline (E00). The FTP weighted vehicle emissions were averaged from three separate FTP75 runs for each fuel.

Using the fuel carbon content and the emissions results from the test vehicles, the following is a table of the calculated difference between E20 and gasoline fuel economy based on the FTP75 emissions results.

Table 3: Change in Fuel Economy – Gasoline vs. E20

ID	Vehicle type	Δ fuel economy w.r.t gasoline
3562	1998 Ford F150	-6.7%
3675	2000 Chevy Impala	-6.1%
4029	2001 Ford F250	-7.2%
4030	2001 Ford F250	-4.8%
4066	2001 Chevy Silverado	-5.8%
4075	2001 Chevy Blazer	-3.9%
4126	2002 G3500 Van	-4.8%
4137	2002 Ford F250	-7.3%
4140	2002 K1500	-5.1%
4230	2004 Ford F250	-4.0%
	Average	-5.6%

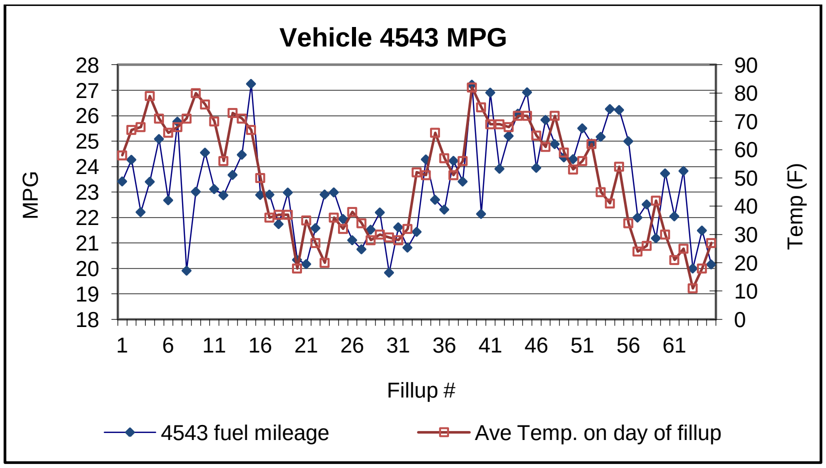
The vehicles tested had an average 5.6 percent reduction in fuel economy running on E20 as compared to running on gasoline.

On-Road Vehicle Fuel Economy

Though the theoretical and experimentally derived fuel economies are good indicators, they are not fully representative of the actual fuel economy experienced by the consumer. The fuel economy is dramatically impacted by how the vehicle is used. The EPA lists quick acceleration, heavy braking, excessive idling, high speed driving, frequent short trips, terrain, and using 4-wheel drive as some conditions that can reduce fuel economy.

Along with driving profile, the EPA also lists cold weather as a condition that can cause reduced fuel economy. The fluctuation of fuel economy with weather was seen in the Monroe County historical data for the different vehicles. Figure 7 is an example chart of the on-road fuel economy for vehicle 4543 plotted with the average temperature on the day the vehicle was refueled. There is a good correlation between the change in fuel economy and the change in outside temperature, with a significant reduction in fuel economy during the winter compared to the summer season. All "on-road" fuel economy data was therefore only used in the calculations if there was an entire year of data to average out all seasonal effects.

Figure 7: Seasonal Change in Temperature and Fuel Economy



For the on-road portion of this study, vehicles were selected that had well-documented fuel usage and servicing histories and were maintained to the manufacturer recommended maintenance schedule. Vehicle odometer and fueling volume were collected through the PetroVend fuel control system and made available through cooperation with the County. Only vehicles with one calendar year of consecutive "gasoline only" fill-ups and one calendar year of consecutive "ethanol containing fuel only" fill-ups were considered for this study. The ground rule established for this study was that each vehicle needed a minimum of twenty fueling events on each fuel to be considered. This provided a sufficient frequency for a sound data set. The gasoline fuel economy was therefore compared with the ethanol containing fuel economy within the same vehicle.

RIT evaluated the on-road fuel economy data for the entire Monroe County flex fuel and conventional gasoline vehicle fleets. Data was collected and stored in an RIT database and data integrity verified. All outliers were identified, interrogated and discarded if the data was a true outlier.

Of the 103 flex fuel vehicles in the County fleet, 27 met the above requirements. They had a total of 1230 gasoline fueling events consuming a total of 15,739 gallons, and a total of 1466 E85 fueling events consuming a total of 18,941 gallons. These vehicles averaged a 14.0 percent reduction in fuel economy using E85 compared to using E00 gasoline, with all 27 vehicles experiencing less of a fuel economy reduction than predicted by the fuel energy content. (refer to Figure 8). Individual vehicle data is in Appendix B.

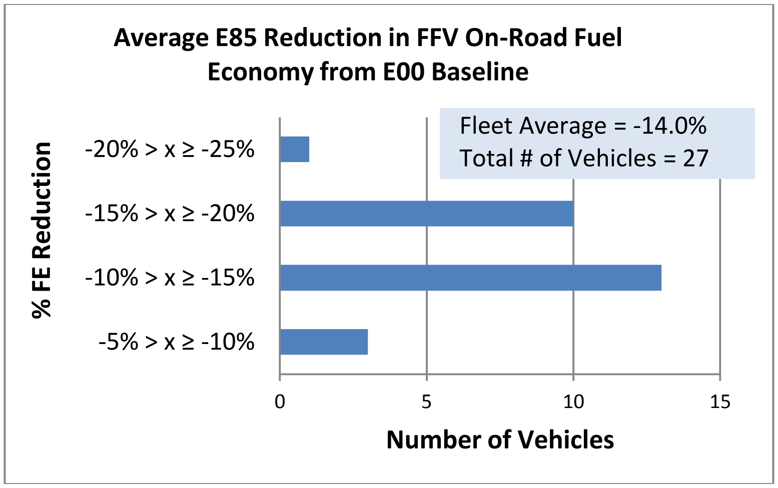


Figure 8: Average E85 Fuel Economy Reduction

Monroe County E20 study vehicles were subjected to the same data integrity requirements as the E85 flex fuel vehicles above. Of the 400 conventional vehicles in the County fleet fueling with E20, 47 met the requirements. They had a total of 2428 gasoline fueling events consuming a total of 39,977 gallons, and a total of 2368 E20 fueling events consuming a total of 38,581 gallons. These vehicles averaged a 5.9 percent reduction in fuel economy using E20 compared to using E00 gasoline (refer to figure 9). Individual vehicle data is presented in Appendix C.

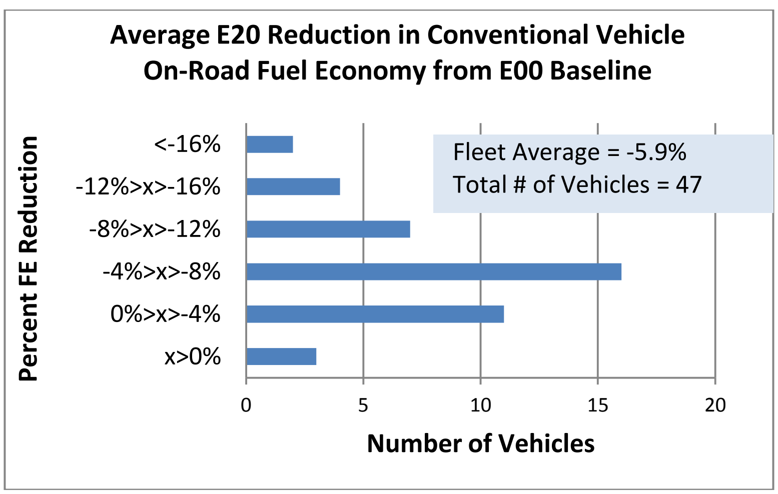


Figure 9: Average E20 Fuel Economy Reduction

Ethanol Cost per Mile

The question remains: are ethanol based fuels cost effective to the consumer? Ethanol fuels are typically less expensive than conventional gasoline; however, given that there is a measureable reduction in fuel economy with ethanol blends and E85 in particular, it is challenging for the consumer to balance that mileage reduction against the difference in pump price across all the fuels. The price of fuel is extremely volatile with many factors influencing what consumers pay at the pump. The price of regular conventional gasoline for example fluctuated almost $2.50 per gallon over the course of only six months of this study from a high of $4.05 per gallon in July 2008 to a low of $1.59 per gallon in December 2008.[11]

Table 4 contains the national monthly average price for gasoline and E85 for the last two years[12] with the price for each fuel plotted against the other for each month in figure 10. The price of E85 has a 99.4 percent correlation compared to the price of conventional gasoline. This level of correlation shows a significant dependence.

Table 4: National Fuel Prices

	Monthly average gas	Monthly average E85	National average price delta
3/1/2008	$3.17	$2.67	15.77%
4/1/2008	$3.43	$2.90	15.45%
5/1/2008	$3.79	$3.13	17.41%
6/1/2008	$3.99	$3.29	17.54%
7/1/2008	$3.97	$3.28	17.38%
8/1/2008	$3.71	$3.08	16.98%
9/1/2008	$3.67	$3.00	18.26%
10/1/2008	$2.86	$2.37	17.13%
11/1/2008	$2.00	$1.80	10.00%
12/1/2008	$1.63	$1.57	3.68%
1/1/2009	$1.81	$1.64	9.39%
2/1/2009	$1.90	$1.72	9.47%
3/1/2009	$1.94	$1.73	10.82%
4/1/2009	$2.03	$1.80	11.33%
5/1/2009	$2.36	$1.94	17.80%
6/1/2009	$2.68	$2.20	17.91%
7/1/2009	$2.48	$2.08	16.13%
8/1/2009	$2.59	$2.10	18.92%

[11] Energy Information Administration, Retail Gasoline Historical Prices, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.html

[12] www.e85prices.com

	Monthly average gas	Monthly average E85	National average price delta
9/1/2009	$2.51	$2.06	17.93%
10/1/2009	$2.55	$2.13	16.47%
11/1/2009	$2.60	$2.23	14.23%
12/1/2009	$2.56	$2.30	10.16%
1/1/2010	$2.67	$2.32	13.11%
2/1/2010	$2.60	$2.21	15.00%
3/1/2010	$2.75	$2.25	18.18%
		average	14.67%

It is highly unlikely that this level of dependence over two years is naturally occurring. The basis cost of gasoline and the basis cost of ethanol are derived from different feed stock, different manufacturing processes, involving different corporations, different infrastructure and transportation, and different tax structure. A high level of dependence with the different cost basis demonstrates that there are market forces tying the cost of ethanol fuel to the cost of gasoline. Additionally, a linear curve fit shows that the cost of E85 is about 16 percent less than the cost of gasoline, which keeps the operating cost of E85 nearly breakeven to a slight premium over gasoline when adjusted for the on-road fuel economy (calculated previously at 14 percent less than the fuel economy of gasoline).

Fuel Price Relationship between Gasoline and Ethanol Fuel

It was estimated by the US Department of Energy that only 450,000 of the 7,100,000 flex fuel

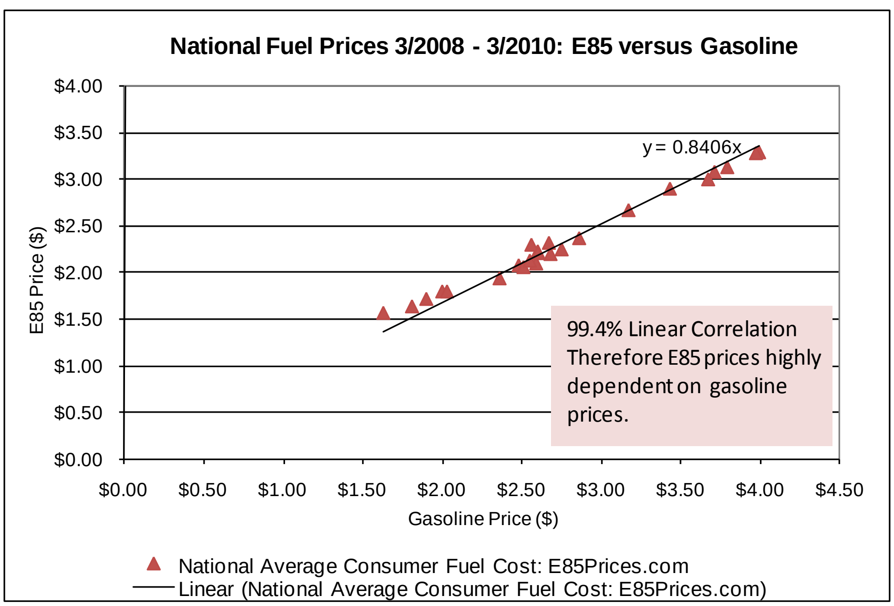


Figure 10: National Fuel Prices

vehicles on the road in 2008 were used as alternative-fuel vehicles filling up on E85 resulting in only 62 million gasoline-equivalent gallons of ethanol used in E85. By contrast, the volume of ethanol blended with gasoline to make E10 has almost reached the upper limit with almost all conventional gasoline containing ethanol (the so-called "blend wall") and 99 percent of all ethanol sold as transportation fuel in 2008 sold into E10 (6.4 billion gasoline-equivalent gallons of ethanol used in E10).[13] Since the operating cost of E85 was shown to be nearly breakeven to gasoline when adjusted for on-road fuel economy and the widespread use of E10 demonstrates the consumer acceptance of ethanol fuel. This raises the question of why the lack of E85 sales.

Since ethanol is essentially an agricultural vs. petroleum product, its cost to produce should not significantly parallel shifts in the value of crude oil or gasoline. There are however some market realities:

- The estimated 138 billion gallons of gasoline consumed in the U.S. in 2009 far overshadows the 10.8 billion gallons of ethanol consumed for fuel.[14] Gasoline is therefore the clear driver of market rates over ethanol.
- There is an energy difference between gasoline and ethanol. This study showed the difference in energy content results in about 14-26 percent fewer miles per gallon when fueled with E85. This energy difference needs to be accounted for when pricing the fuels.
- Federal mandates to increase the use of biofuels result in an increased amount of ethanol demand to be blended with gasoline.
- Industry wants to sell more of a higher-profit product (basic economics).

Simplifying the economic relationship between gasoline and ethanol, consider the retail price of gasoline (G), the retail price of denatured ethanol (E), the volume percent of denatured ethanol (V), and the resulting retail price of the ethanol containing fuel at the pump (P).

In a perfect world, the relationship between the retail prices of the commodity ethanol and gasoline should predict the retail price of ethanol containing fuel at the pump such that:

$$((1-V)\times G)+(V\times E)=P \qquad \textbf{\{1\}}$$

Therefore the resulting formulas for the two main ethanol containing fuels on the market are:

$$0.9G_{10}+0.1E_{10}=P_{10} \qquad \textbf{\{2\}}$$

For the retail price of E10:

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[13] .S Energy Information Administration, Annual Energy Review 2009, DOE/EIA-0384 (2009), August 2010, pg 149, Table 5.11 Petroleum Products Supplied by type, Selected Years, 1949-2009 (2009: 8,986,000 barrels per day of motor gasoline). Table 10.3 Fuel Ethanol Overview, 1981-2009 (2009: 10,847 million gallons consumption)

[14] U.S Energy Information Administration, Annual Energy Review 2009, DOE/EIA-0384 (2009), August 2010, pg 295, Table 10.5 Estimated Number of Alternative-Fueled Vehicles in Use and Fuel Consumption, 1992-2008

$$0.15G_{85} + 0.85E_{85} = P_{85} \quad \{3\}$$

For the retail price of E85:

Assuming that the ethanol is blended with the same priced gasoline, then (G_{10}= G_{85}= G). Note that E10 is currently being sold at the same price of conventional gasoline (G=P_{10}); therefore by default, every gallon of ethanol being sold as a component of E10 is being sold at the same price per gallon as gasoline, or E_{10}=G. Since the phase-in of E10 was gradual with the elimination of MTBE, and the mileage penalty for using E10 vs. gasoline (E00) is almost undetectable by consumers, E10 has now become for most people "conventional" unleaded.

In Figure 7, however, the retail price relationship between gasoline (or E10 since G=P_{10}) and E85, supported by the national average prices over a two year period, has been shown with a 99.4 percent correlation to be:

$$P_{85} = 0.84P_{10} \quad \{4\}$$

Using equation {4} to set the relationship between equations {2} and {3}:

$$0.15G + 0.85E_{85} = 0.84 \times (0.9G + 0.1E_{10}) \quad \{5\}$$

Since G=E_{10}, solving equation {5} for the relationship between the retail price of ethanol in E85 compared to the retail price of ethanol in E10 yields:

$$E_{85} = 0.812E_{10} \quad \{6\}$$

The retail price of the ethanol commodity in E10 is therefore 23 percent larger than the retail price of the ethanol commodity in E85. Since the wholesale price of ethanol in E10 is the same as the wholesale price of ethanol in E85, the maximum profit on ethanol in fuel is realized by selling E10.

It is logical therefore that if more profit is made on ethanol by selling E10, most of the ethanol sales will be driven to E10. As a result of the current price structure, 99 percent of all ethanol sold as transportation fuel in 2008 was sold into E10.

This relationship will likely hold for mid-level blends such as E20. Since there is only a 6 percent drop in fuel economy from regular gasoline, the retail price of E20 can be priced near the retail price of conventional gasoline (which is now almost exclusively E10), thereby maximizing the profit margin on the ethanol portion. The mileage penalty for using E20 vs. E10 is roughly the same as for E10 vs. E00 and will likely also go undetected as consumers purchase new vehicles, change driving habits or routes, etc. It is likely therefore that this is one of the major reasons the ethanol industry is pushing to maximize the ethanol percent in conventional gasoline rather than increase the consumption of E85.

Discussion

The consumer operating cost (cost per mile) is a function of both the fuel cost, and the fuel economy of the vehicle. A renewable fuel such as ethanol has a lower energy content than conventional gasoline and therefore there is a loss in fuel economy when used in the same vehicle. Consumers should be aware of this reality when they purchase a flex fuel vehicle or use mid-level blends in conventional vehicles.

For the County vehicles tested, the reduction in fuel economy was better than predicted by theoretical reduction in fuel economy calculated from the fuel energy content. The on-road fuel economy for E85 in particular was significantly better than predicted by the energy content.

	E85 fuel economy reduction from gas	E20 fuel economy reduction from gas
Theoretical	-26.0%	-6.8%
Experimental	-26.6%	-5.6%
On-road	-14.0%	-5.9%

The better-than-expected fuel economy penalty has been noted in previous vehicle and engine studies,[15] [16] and while the trend is consistent, there is likely more than one factor causing the effect. As an example, Szybist states that "In practice, CR [compression ratio] in production engines is limited by the ability of gasoline to resist knock, especially at the most knock-prone engine conditions, which are low-speed and high-load". The better-than-expected fuel economy penalty with ethanol fuel for Monroe County vehicles may therefore be explained by the reduced and knock-constrained performance of gasoline, rather than strictly an improvement in performance of ethanol blends.

The fuel economy penalty should be factored into the consumer purchase decision in order to determine the "best value" for the fuel dollar. E85 reduced the County fleet average on-road fuel economy by 14 percent with the energy content reduction of 26 percent. When comparing this penalty to the difference in fuel cost, the operating cost using E85 ranges from just breaking even to requiring a premium. This cost structure has not been enough to incentivize E85 fuel sales as less than 7 percent of the FFVs on the road use E85.

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[15] Hanna, M., Isom, L., Weber, R., Mid-level Ethanol Blend Study: Chassis Dynamometer Study of Flex Fuel Vehicles, September 2009, University of Nebraska – Lincoln.

[16] Szybist, J., Youngquist, A., Wagner, R., Moore, W., Foster, M., Confer, K., "Investigation of Knock limited Compression Ratio of Ethanol Gasoline Blends." SAE Technical Paper 2010-01-0619, 2010

The ethanol content in gasoline designated for conventional vehicles is being maximized; however, even if it is increased to a functional limit, more ethanol use is required to meet the renewable fuels standard in the near future. It was demonstrated however that the industry has more incentive (profit) to sell low level blend fuel rather than E85. The incentive structure should therefore be adjusted to maximize the sale of FFVs and the consumption of E85.

One way to change the cost structure is to adjust the use of the blender's credit. Currently, the blender's credit applies equally to ethanol blended with gasoline in any percentage. If that stays the same, it will likely remain more profitable to make low level ethanol blends such as E10, or E15. One way to change the paradigm is to only apply the blender's credit to ethanol fuel that can only be used in FFVs only. (i.e., greater than the current waiver for conventional vehicles) This would enable a higher profit margin on higher blend ethanol fuels and therefore drive sales of fuels such as E85. The blender's credit for E10 can additionally be abolished because the oxygenate requirement and the RFS more or less mandate the use of E10. The subsidy is no longer necessary on an essentially mandated product. This approach is supported by Babcock[17] who also put forth the idea that the tax credit no longer enhances the economics of blending above the mandated level.

If the U.S. is to achieve more use of biofuels as mandated by the RFS, the blend limit needs to be increased (i.e., through the E15 waiver), and more E85 needs to be sold and consumed. To induce consumers to buy more flex fuel vehicles and use more E85, the cost structure must be changed.

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[17] Babcock, B., Barr, K., Carriquiry M., 2010. "Costs and Benefits to Taxpayers, Consumers and Producers from U.S. Ethanol Policies." Staff Report 10-SR 106, Center for Agricultural and Rural Development, Iowa State University, Ames, IA.

Vehicle Durability

One way the operator knows that the vehicle is not operating to specification is through the vehicle on-board diagnosis (OBD) system. The engine electronic control unit ECU is required by EPA regulation to use on-board diagnosis (OBD) functions to monitor all of the systems and components within the vehicle whose failure could lead to substantial increases in pollutant emissions. Systems that are commonly monitored are: fuel system, lambda (oxygen) sensors, exhaust-gas recirculation, engine cooling, cold-starting emission-control system, and the catalytic converter.[18] An error occurs once defined diagnostic thresholds are exceeded, typically triggering the Malfunction Indicator Light (MIL), or the “check engine” light. Occasional flashes will show a momentary malfunction. If it stays on, the problem is of a more serious nature, affecting the emissions output or safety of the vehicle. The OBDII regulation prescribes standardized diagnostic trouble codes (DTC) as defined for the SAE in accordance with ISO 15031[19] ensuring that stored error codes can be accessed using standard scan tools.

The OBD function offered us a unique opportunity to inspect and compare the vehicle operation on each fuel. Many of the systems monitored by OBD also control vehicle drivability. The ECM for example monitors the exhaust stream and adjusts the air/fuel ratio to optimize the catalytic converter efficiency. The oxygen sensor measures the amount of oxygen remaining after combustion in the exhaust stream. From this information, the ECM controls the injection duration to achieve the stoichiometric ideal air-fuel ratio.

To account for wear and tear, altitude or air density, fuel quality, and failed components, the vehicle has an adaptive fuel strategy which detects and corrects for deviations from stoichiometry while running in closed loop.[20] These corrections to the injection duration are stored in Keep Alive Memory as long term fuel trim corrections. If components continue to change beyond normal limits or if a malfunction occurs, the long-term fuel trim values will reach a set limit where the adaptive fuel strategy can no longer compensate for additional fuel system changes. Long term fuel trim corrections at their limits, in conjunction with a set deviation in short-term fuel trim, indicate a rich or lean fuel system malfunction.[21] A rich or lean fuel system malfunction will cause many of the listed drivability issues.

There are many sensors monitored by the OBD. RIT used a Modis scan tool to read the setting on many of these sensors. The Modis is hand-held diagnostic instrumentation platform that incorporates on-board diagnostic hardware/software for analyzing complex systems aboard current domestic and import vehicles. It can locate, connect, test, and troubleshoot components using a

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[18] Robert Bosch GmbH, *Gasoline-Engine Management*, 2nd Edition, Bentley Publishers, 2004, pg. 312.

[19] ISO 15031-6:2005, Road vehicles - Communication between vehicle and external equipment for emissions-related diagnostics -- Part 6: Diagnostic trouble code definitions

[20] *2004 MY OBD System Operation Summary for Gasoline Engines*, Ford Motor Company http://www.motorcraftservice.com/vdirs/diagnostics/pdf/OBDSM407.pdf

[21] Vehicle information obtained from: http://www.aa1car.com/library/oemwebsites.htm

built-in 4-channel digital scope with multiple secondary ignition capabilities and a digital graphing multimeter, and offers ports for adding optional diagnostic hardware.

Diagnostic Trouble Codes

Monroe County installed Networkcar's® Networkfleet™ wireless vehicle management system on all evaluation vehicles. This system transmits both vehicle location and performance information on a regular basis and enables fleet managers to easily locate vehicles in real-time and view specific vehicle data such as current location, fuel consumption, mileage and speed.

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The Networkfleet system also provides the diagnostic trouble code (DTC) and a description identifying the specific nature of the vehicle problem. Networkfleet also provides two general forms of service-related alerts:

- Active Alerts: Indicate a problem has been detected within a vehicle.
- Pending Alerts: Indicate a problem that might occur in a vehicle (these service alerts are available on the fleet website that is maintained by Networkfleet).

The following table contains the alerts provided by the Networkfleet system.

ID	Networkcar Alerts	Issue
3562	P0155: O2 Sensor Heater Circuit Malfunction (Bank 2 Sensor 1). Engine may not be consuming fuel efficiently Initial Read: 02/20/2008 08:25:14 AM C1341: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 02/26/2008 07:20:01 AM P2c41: Unknown DTC. Vehicle is reporting a potential sensor malfunction. Initial Read: 02/26/2008 07:20:01 AM P2c33: Unknown DTC. Vehicle is reporting a potential sensor malfunction. Initial Read: 02/26/2008 07:20:01 AM P0135: O2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 1) Engine may not be consuming	Oxygen sensor, possible lean condition

ID	Networkcar Alerts	Issue
	fuel efficiently. Initial Read: 05/13/2008 07:36:38 AM C1341: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 01/08/2009 07:22:49 AM P2c41: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 01/08/2009 07:22:49 AM P2c33: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 01/08/2009 07:22:49 AM C1341: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 06/28/2009 06:14:14 AM P2c41: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 06/28/2009 06:14:14 AM P2c33: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 06/28/2009 06:14:14 AM	
3675	P0140: O2 Sensor Circuit No Activity Detected (Bank 1 Sensor 2) Engine may not be consuming fuel efficiently. Initial Read: 04/02/2008 12:52:09 PM P0140: O2 Sensor Circuit No Activity Detected (Bank 1 Sensor 2) Engine may not be consuming fuel efficiently. Initial Read: 05/02/2008 03:31:38 PM P0140: O2 Sensor Circuit No Activity Detected (Bank 1 Sensor 2) Engine may not be consuming fuel efficiently. Initial Read: 05/28/2008 03:51:43 PM P0140: O2 Sensor Circuit No Activity Detected (Bank 1 Sensor 2). Engine may not be consuming fuel efficiently. Initial Read: 07/21/2008 10:02:47 AM P0140: O2 Sensor Circuit No Activity Detected (Bank 1 Sensor 2). Engine may not be consuming fuel efficiently. Initial Read: 11/21/2008 01:12:34 PM	Oxygen sensor, possible lean condition
4029	C1341: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 11/18/2008 07:45:39 AM P2c41: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 11/18/2008 07:45:39 AM P2c33: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 11/18/2008 07:45:39 AM	
4030	No Alerts	
4066	ACTIVE ALERT: P1404: Exhaust Gas Recirculation System Valve 2. Vehicle is not processing exhaust gasses correctly. Initial Read: 12/21/2007 06:47:29 AM P1404: Exhaust Gas Recirculation System Valve 2. Vehicle is not processing exhaust gasses correctly Initial Read: 01/07/2008 09:14:11 AM 3/04/08 User Observation: check engine light lit P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 03/18/2008 04:03:16 PM ACTIVE ALERT: P0442: Evaporative Emission Control System Leak Detected (small leak). Engine exhaust system may be releasing excessive hydrocarbons Initial Activity: 4/28/09 01:12 PM at 143264 miles P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 06/15/2009 08:59:47 PM P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 06/24/2009 02:39:52 PM ACTIVE ALERT: P0442: Evaporative Emission Control System Leak Detected (small leak). Engine exhaust system may be releasing excessive hydrocarbons Initial Activity: 7/1/09 07:37 AM at 146523 miles C1341 CHEVROLET: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 07/05/2009 07:41:04 AM P2c41 CHEVROLET: Unknown DTC. Vehicle is reporting a potential sensor malfunction. Initial Read: 07/05/2009 07:41:04 AM	Cylinder misfire, possible lean condition

ID	Networkcar Alerts	Issue
	P2c33 CHEVROLET: Unknown DTC. Vehicle is reporting a potential sensor malfunction. Initial Read: 07/05/2009 07:41:04 AM P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 07/06/2009 06:59:18 PM P0442: Evaporative Emission Control System Leak Detected (small leak) Engine exhaust system may be releasing excessive hydrocarbons Initial Read: 07/11/2009 07:33:09 AM P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 07/13/2009 10:12:50 PM ACTIVE ALERT: P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 07/18/2009 07:00:56 PM P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 07/19/2009 03:00:10 PM	
4075	P0135: O2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 1) Engine may not be consuming fuel efficiently. Initial Read: 06/29/2009 04:37:41 PM P0141: O2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 2) Engine may not be consuming fuel efficiently. Initial Read: 06/29/2009 04:41:43 PM P0155: O2 Sensor Heater Circuit Malfunction (Bank 2 Sensor 1) Engine may not be consuming fuel efficiently. Initial Read: 06/29/2009 04:35:40 PM ACTIVE ALERT: P0135: O2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 1) Engine may not be consuming fuel efficiently Initial Activity: 6/30/09 07:32 AM at 60907 miles ACTIVE ALERT: P0141: O2 Sensor Heater Circuit Malfunction (Bank 1 Sensor 2) Engine may not be consuming fuel efficiently Initial Activity: 6/30/09 07:36 AM at 60908 miles ACTIVE ALERT: P0155: O2 Sensor Heater Circuit Malfunction (Bank 2 Sensor 1) Engine may not be consuming fuel efficiently Initial Activity: 6/30/09 07:32 AM at 60907 miles	Driver comment: the "service engine soon" light came on this morning on my way to work. I was going to call and make a service appt. The truck ran fine on the way in - didn't notice any issues - Still - this is pretty cool.
4126	P0306: Cylinder 6 Misfire Detected. Engine may not be consuming fuel efficiently Initial Read: 11/07/2008 11:29:08 AM P1345: VVT Sensor Circuit Malfunction (Bank 1). Engine may not be consuming fuel efficiently. Initial Read: 02/04/2009 10:12:22 AM P0306: Cylinder 6 Misfire Detected. Engine may not be consuming fuel efficiently Initial Read: 05/21/2009 02:21:22 PM P0306: Cylinder 6 Misfire Detected. Engine may not be consuming fuel efficiently Initial Read: 06/26/2009 02:25:43 PM ACTIVE ALERT P0306: Cylinder 6 Misfire Detected. Engine may not be consuming fuel efficiently. Initial Activity: 6/29/09 07:35 AM at 97540 miles P0306: Cylinder 6 Misfire Detected. Engine may not be consuming fuel efficiently Initial Read: 07/21/2009 09:56:06 AM	Unit was in the shop for coolant leak , Pressure tested cooling system Intake Gasket leaking . Possibly rich mixture once intake reinstalled and ignition timing reset . Should be fine now . Repair was completed 02/ 04 /09
4137	C1341: Unknown Chassis DTC Vehicle is reporting a potential chassis sensor malfunction Initial Read: 09/12/2008 01:28:25 PM P2c41: Unknown DTC Vehicle is reporting a potential sensor malfunction. Initial Read: 09/12/2008 01:28:25 PM P2c33: Unknown DTC Vehicle is reporting a potential sensor malfunction. Initial Read: 09/12/2008 01:28:25 PM C1341: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 11/21/2008 10:35:43 AM P2c41: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 11/21/2008 10:35:43 AM	

ID	Networkcar Alerts	Issue
	P2c33: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 11/21/2008 10:35:43 AM	
4140	P0300: Random/Multiple Cylinder Misfire Detected. Engine may not be consuming fuel efficiently. Initial Activity: 12/21/07 08:13 AM at 51666 miles P0301: Cylinder 1 Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 02/25/2008 01:19:47 PM C1341 GMC: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 05/07/2009 11:21:29 AM P2c41 GMC: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 05/07/2009 11:21:29 AM P2c33 GMC: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 05/07/2009 11:21:29 AM	Cylinder misfire, possible lean condition
4230	P0303: Cylinder 3 Misfire Detected. Engine may not be consuming fuel efficiently. Initial Read: 08/04/2008 08:03:39 AM P0316: Misfire Detected on Startup (First 1000 Revolutions). Engine may not be consuming fuel efficiently. Initial Read: 08/04/2008 08:03:39 AM C1341: Unknown Chassis DTC. Vehicle is reporting a potential chassis sensor malfunction. Initial Read: 2/6/09 08:18 AM at 45279 miles P2c41: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 2/6/09 08:18 AM at 45279 miles P2c33: Unknown DTC. Vehicle is reporting a potential sensor malfunction Initial Read: 2/6/09 08:18 AM at 45279 miles P1450: Unable to bleed up fuel tank vacuum. Engine may not be consuming fuel efficiently. Initial Read: 05/15/2009 07:43:05 AM	Cylinder misfire, possible lean condition

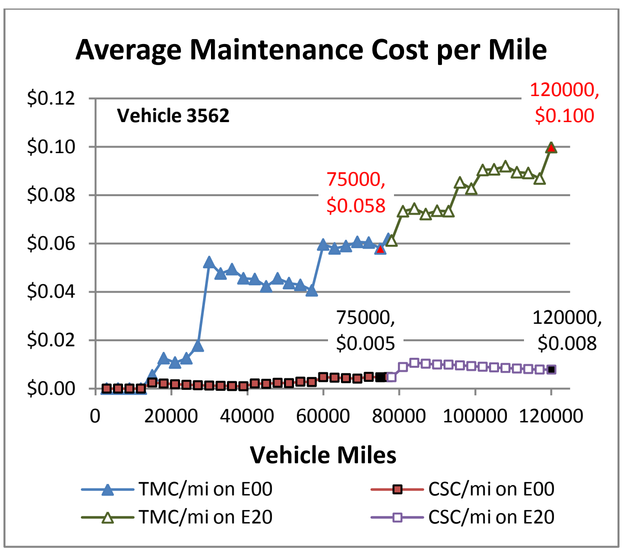
Exploratory Fleet Maintenance Cost

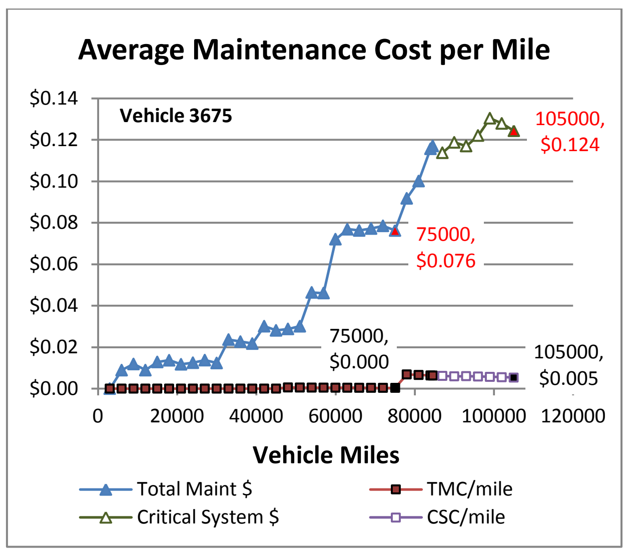
A significant portion of the fleet operating cost is the cost to keep the vehicles at peak operating condition. There are two components to typical vehicle maintenance: scheduled or preventative maintenance, such as changing the engine oil every few thousand miles, and unscheduled or reactive maintenance, such as fixing a flat tire. As a policy, Monroe County maintains their vehicles strictly according to the manufacturer recommendations for preventive maintenance. The County uses a multi-site fleet management system (FleetMax™) to track all maintenance work orders, vehicle maintenance events, and part and labor cost. CSM was granted access to all required vehicle records for this evaluation.

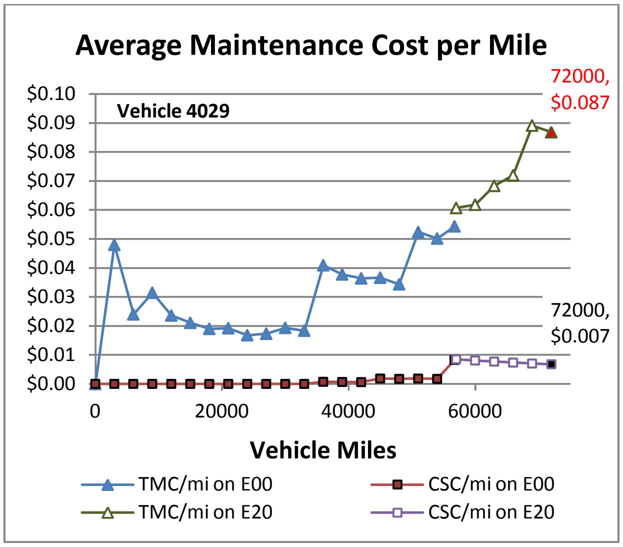
The cost of maintenance was normalized on a per mile basis. Total Maintenance Cost (TMC) included the cost of all maintenance completed on a given vehicle. This data however did not provide the required detail since a significant portion of the maintenance cost is not fuel related. Examples of non-fuel related maintenance included upgrades performed to vehicles to enable specific fleet missions (such as adding light bars or snow plows), replacement of normal wear out items such as tires or breaks, and single maintenance events such as collision repair.

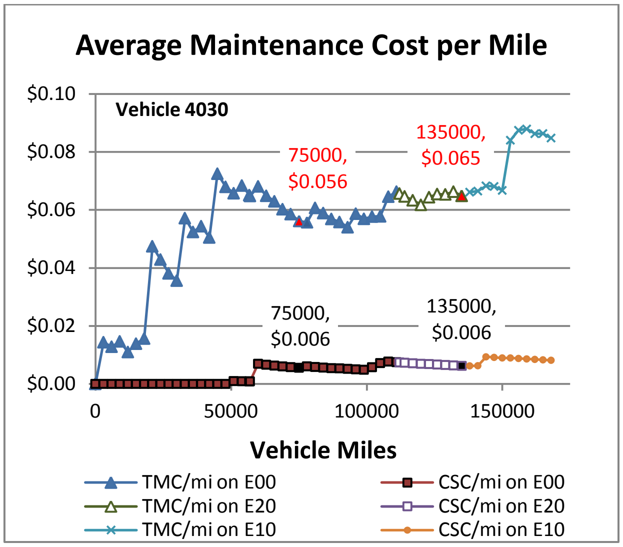
To gain better insight on the specific impact of fuel choice, the maintenance cost was further delineated into the cost to maintain the critical systems. Critical systems were identified as any system that came in contact with the fuel, or byproducts of the fuel. Critical systems included the engine, fuel, and the exhaust systems. This maintenance cost was identified as the Critical System Maintenance Cost (CSMC). A “critical failure” was further identified as an unscheduled maintenance event that happened within the critical system. Vehicle reliability was calculated by looking at unscheduled maintenance and calculating the time between events. This was referred to as Mean Time Between Critical Failure (MTBCF).

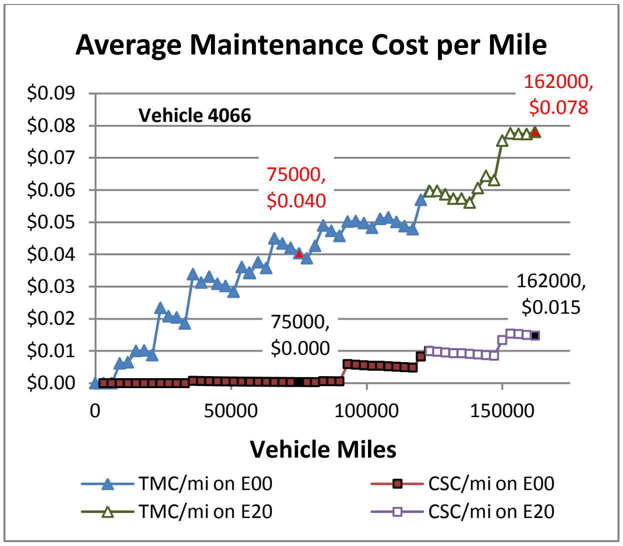
Vehicle ID	Vehicle	VIN	Odometer reading at start of E20 test	First fill data on E20	Date at end of E20	Odometer reading at end of E20	Miles on E20	Gallons of fuel used
3562	1998 Ford F150	2FTZF1724WCA95392	77158	2/20/08	2/22/11	118757	41599	3250
3675	2000 Chevy Impala	2G1WF52E2Y9383691	84567	2/20/08	2/11/11	104468	19901	816
4029	2001 Ford F250	1FTNF21L81EC69442	56282	2/20/08	1/31/11	71959	15677	1568
4030	2001 Ford F250	1FTNX21LX1EC69441	115013	2/19/08	6/30/09	135271	20258	1608
4066	2001 Chevy Silverado	1GCEK19V11E321845	123298	2/25/08	2/18/11	161410	38112	2558
4075	2001 Chevy Blazer	1GNDT13W31K241742	51328	2/17/08	2/16/11	72590	21262	1296
4126	2002 Chevy G3500	1GCHG35R421200285	86467	2/19/08	2/16/11	110727	24260	1881
4137	2002 Ford F250	1FTNX21LX2EC83681	122192	2/19/08	2/14/11	139724	17532	1789
4140	2002 GMC Sierra1500	1GTEK14V92Z328088	52458	2/19/08	2/15/11	78733	26275	1850
4230	2004 Ford F250	1FTNX20L84ED46264	32452	2/19/08	2/4/11	68853	36401	3111
						Total	261277	19727

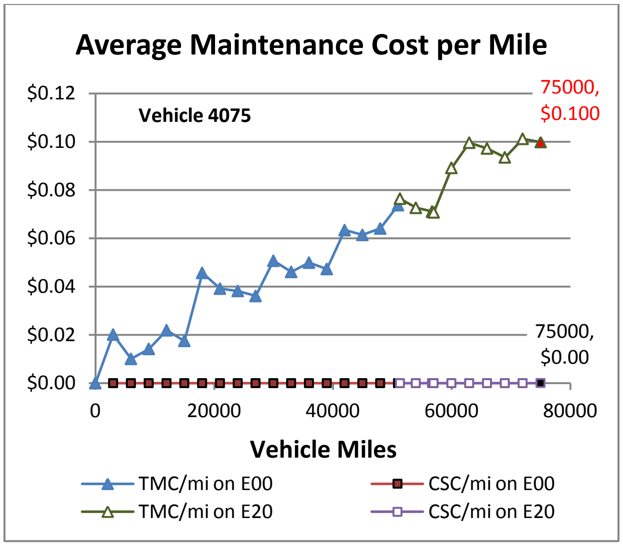


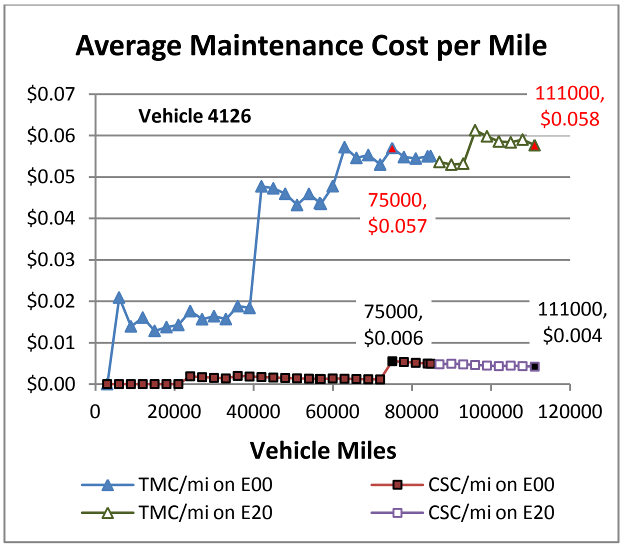


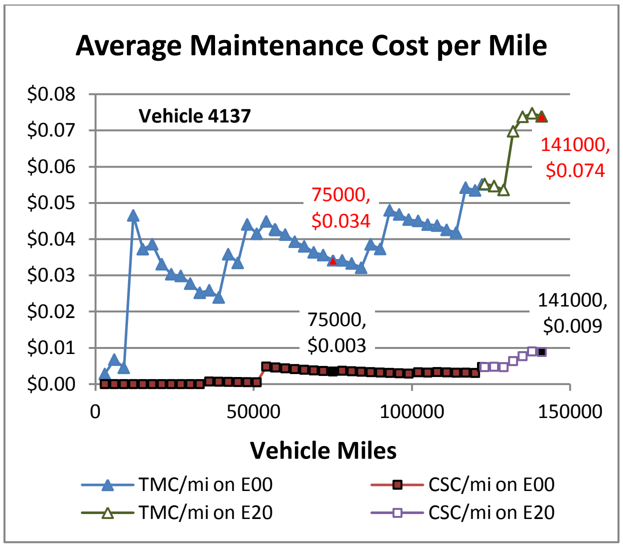

Average Maintenance Cost per Mile
Vehicle 4029
72000, $0.087
72000, $0.007
Vehicle Miles
TMC/mi on E00
CSC/mi on E00
TMC/mi on E20
CSC/mi on E20

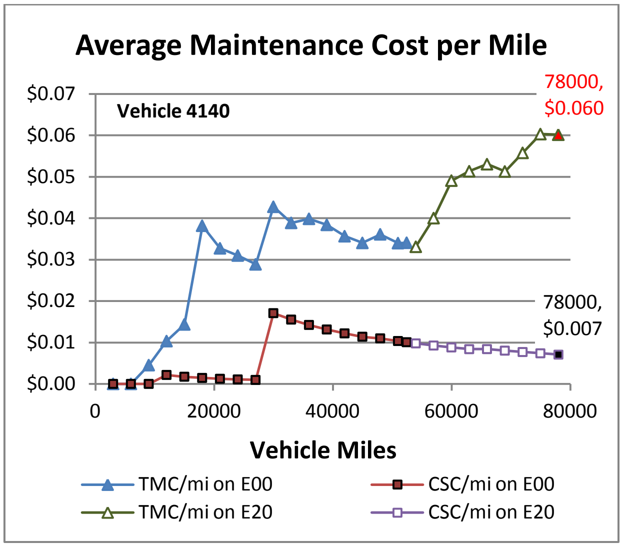

Average Maintenance Cost per Mile
Vehicle 4030
75000, $0.056
135000, $0.065
75000, $0.006
135000, $0.006
Vehicle Miles
TMC/mi on E00
CSC/mi on E00
TMC/mi on E20
CSC/mi on E20
TMC/mi on E10
CSC/mi on E10

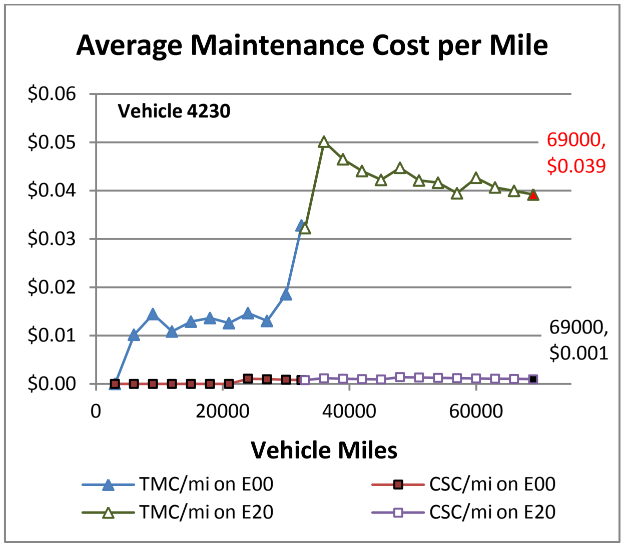

Average Maintenance Cost per Mile
Vehicle 4066
162000, $0.078
75000, $0.040
162000, $0.015
75000, $0.000
Vehicle Miles
TMC/mi on E00
CSC/mi on E00
TMC/mi on E20
CSC/mi on E20


Average Maintenance Cost per Mile
Vehicle 4075
75000, $0.100
75000, $0.00
Vehicle Miles
TMC/mi on E00
CSC/mi on E00
TMC/mi on E20
CSC/mi on E20


Average Maintenance Cost per Mile
Vehicle 4126
111000, $0.058
75000, $0.057
75000, $0.006
111000, $0.004
Vehicle Miles
TMC/mi on E00
CSC/mi on E00
TMC/mi on E20
CSC/mi on E20


Average Maintenance Cost per Mile
Vehicle 4137
141000, $0.074
75000, $0.034
141000, $0.009
75000, $0.003
Vehicle Miles
TMC/mi on E00
CSC/mi on E00
TMC/mi on E20
CSC/mi on E20





Vehicle ID	Vehicle	Odometer reading at start of E20 test	First fill data on E20	Date at end of E20	Odometer reading at end of E20	Miles on E20	Gallons of fuel used	Maint $ at 75k miles	Critical Maint $ at 75k miles
3562	1998 Ford F150	77158	2/20/08	2/22/11	118757	41599	3250	5.8¢/mi	0.5¢/mi
3675	2000 Chevy Impala	84567	2/20/08	2/11/11	104468	19901	816	7.6¢/mi	0.0¢/mi
4029	2001 Ford F250	56282	2/20/08	1/31/11	71959	15677	1568	8.7¢/mi	0.7¢/mi
4030	2001 Ford F250	115013	2/19/08	6/30/09	135271	20258	1608	5.6¢/mi	0.6¢/mi
4066	2001 Chevy Silverado	123298	2/25/08	2/18/11	161410	38112	2558	4.0¢/mi	0.0¢/mi
4075	2001 Chevy Blazer	51328	2/17/08	2/16/11	72590	21262	1296	10.0¢/mi	0.0¢/mi
4126	2002 Chevy G3500	86467	2/19/08	2/16/11	110727	24260	1881	5.7¢/mi	0.6¢/mi
4137	2002 Ford F250	122192	2/19/08	2/14/11	139724	17532	1789	3.4¢/mi	0.3¢/mi
4140	2002 GMC Sierra1500	52458	2/19/08	2/15/11	78733	26275	1850	6.0¢/mi	0.7¢/mi
4230	2004 Ford F250	32452	2/19/08	2/4/11	68853	36401	3111	3.9¢/mi	0.1¢/mi
Total		801215			1062492	261277	19727		

Monroe County Maintenance Records

Reliability is defined as the probability that a component part, equipment, or system will satisfactorily perform its intended function under given circumstances, such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specified period of time. Monroe County vehicles were maintained according to manufacturer recommendations throughout the evaluation; therefore, in theory, the vehicle availability and up-time should be equivalent on gasoline as it is on E20.

As a policy, Monroe County maintains their vehicles strictly according to the manufacturer recommendations for preventive maintenance. The County uses a multi-site fleet management system to track all fueling (OPW Fuel Management Systems, PetroVend) and vehicle maintenance events and part and labor cost (FleetMax™). RIT was granted access to all required vehicle records.

Vehicle reliability was calculated by looking at unscheduled maintenance and calculating the time between events. This was referred to as Mean Time Between Critical Failure (MTBCF).

Besides the regularly scheduled maintenance, only one test vehicle had unscheduled maintenance was performed during the E20 testing phase[22]. The test vehicles had unscheduled maintenance events while running on gasoline in a time frame greater than what was traveled on E20; therefore, more time is required to use MTBCF as a metric to look for reliability differences.

Vehicle ID	Fuel Type	Date of Analysis	Odometer reading at fuel switch	Miles on gasoline	Total Maint Costs	Critical System Costs	Critical Failure Costs	Crit Sys Cost Per Mile	Number Crit Fail	Mileage at critical failure
3562	E0		77158	77158	$7,353.05	$508.48	$140.00	$0.0096	1	41865
4029	E0		57041	57041	$4,305.11	$116.44	$0.00	$0.0020	0	-
4030	E0		115013	115013	$7,632.19	$1,016.87	$367.06	$0.0089	1	59067
4066	E0		123298	123298	$7,622.44	$1,310.20	$72.00	$0.0106	1	121944
4075	E0		52459	52459	$3,993.93	$0.00	$0.00	$0.0000	0	-
4126	E0		86467	86467	$5,366.42	$430.46	$282.92	$0.0054	1	67930
4137	E0		122192	122192	$7,617.72	$610.61	$31.00	$0.0050	1	75452
4140	E0		52458	52458	$4,407.78	$512.16	$460.56	$0.1515	1	-
	AVG		85760.8	85760.8	$6,037.33	$563.15	$169.19	$0.0074	0.750	73251.6

Vehicle ID	Fuel Type	Date of Analysis	Odometer reading at end of E20 test	Miles on E20	Total Maint Costs	Critical System Costs	Critical Failure Costs	Crit Sys Cost Per Mile	Number Crit Fail	Mileage at critical failure
3562	E20		88443	11285	$2,234.61	$243.88	$0.00	$0.0216	0	-
4029	E20		63575	6534	$7,380.52	$0.00	$0.00	$0.0000	0	-
4030	E20		135271	20258	$1,382.99	$30.40	$0.00	$0.0015	0	-
4066	E20		142542	19244	$3,955.33	$800.00	$754.00	$0.0416	1	25685
4075	E20		61012	8553	$2,543.02	$0.00	$0.00	$0.0000	0	-
4126	E20		97933	11466	$1,218.63	$31.00	$0.00	$0.0027	0	-
4137	E20		131201	9009	$1,594.89	$46.00	$0.00	$0.0051	0	-
4140	E20		60188	7730	$1,713.31	$46.00	$0.00	$0.0060	0	-
	AVG		97520.6	11759.9	$2,752.91	$149.66	$94.25	$0.0127	0.125	25685

Exploratory Fleet Conclusions

The ten vehicle exploratory fleet experienced tail pipe emissions comparable to emissions on gasoline, had some Networkcar alerts, however none out of the ordinary, required no additional maintenance, and had good driveability. It was therefore considered a low risk to move fleet the

[22] Vehicle 3562 had the gas tank and emissions system replaced.

entire Monroe County gasoline fleet to E20. It is recommended to continue monitoring exploratory fleet, and perform an additional round of emissions testing measuring specifically for degradation.

Vehicle Drivability

Drivability describes how dependably a vehicle responds to driver inputs and general conditions. Drivability is typically a subjective assessment of the operator's perception of the vehicle's characteristics such as: cold and hot start performances, crank time, idle quality, and acceleration quality.

Kittelson , et al.[23] at the University of Minnesota were contracted by the State of Minnesota to conduct a drivability evaluation of a vehicle test fleet consisting of 80 university vehicles, comprising 40 pairs of similar vehicles with similar usage patterns. One of each pair of vehicles was fueled with the baseline fuel for the test program (E0) and the other was fueled with the project test fuel (E20). Vehicle drivers were asked to complete daily log sheets indicating any drivability problems that occurred. These lay driver evaluations were compiled throughout the study, together with maintenance and fuel consumption data. In addition, trained vehicle drivability raters were contracted to conduct industry standard drivability tests on a subset of the vehicle fleet, with a test series in each season: fall, winter, spring, and summer. Although some differences in performance were observed between vehicles fueled by E0 and E20 by both lay drivers and trained raters, differences in drivability and reliability were small, inconsistent, and not statistically significant.

Monroe County test vehicles were operated by Monroe County employees and driven on public roads in a random manor based on the fleet mission. Each vehicle spent numerous years running on gasoline operated by a known driver set. These drivers were then educated on the project, and asked to participate in an evaluation of their vehicles running on E20. Subjective data was collected on each vehicle through review cards filled out by the operator at each refueling. Additionally, each operator filled out a drivability and performance survey during a mid-program review.

Drivability Survey Results (10-16-08)

The objective of obtaining drivability data is to collect and assimilate the vehicle driving characteristics according to operator opinions. After 8 months of running on E20, the drivers were asked to fill out a drivability survey, rating both the driving characteristics of their vehicles, and their overall satisfaction with their experience using E20 fuel.

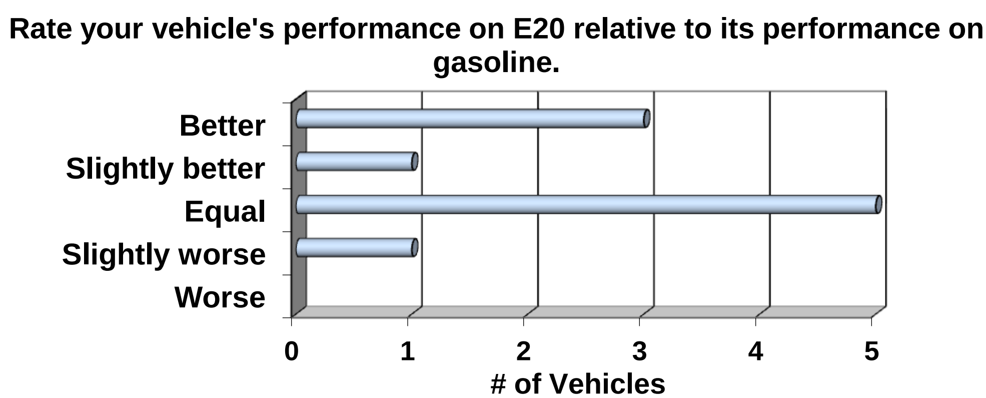
The following table contains the drivability results. The drivers rated each failure mode to the frequency at which the driver experienced the issue. (N-never or not apply, R-rarely, S-sometimes, M-mostly, A-always)

[23] Kittelson, D., Tan, A., Zarling, D., Evans, B., and Jewitt, C.H., *Demonstration and Driveability Project to Determine the Feasibility of Using E20 as a Motor Fuel*, University of Minnesota, Department of Mechanical engineering, Minneapolis, MN. Final report submitted to Minnesota Department of Agriculture. 2007.

Drivability Failure Mode	3562	3675	4029	4030	4066	4075	4126	4137	4140	4230
Extended crank time	N	S	N	N	N	N	S	N	N	N
Rough idle	N	N	S	N	N	N	S	N	N	N
Fast idle	N	N	N	N	N	N	S	N	N	N
Hesitates under acceleration	N	S	N	N	N	N	S	N	N	N
Misses under load	N	R	N	N	N	N	N	N	N	N
Surges at constant speed	N	N	N	N	N	N	N	N	N	N
Limited power	N	N	N	N	N	N	N	N	N	N
Pings or knocks	N	N	N	N	N	N	S	N	N	N
Stalls on deceleration	N	N	N	S	N	N	S	N	N	N
Dieseling	N	R	N	N	N	N	N	N	N	N
Backfires	N	N	N	N	N	N	N	N	N	N

Half the vehicles experienced no issues at all. Vehicles 3675 and 4126 occasionally experienced multiple failure modes.

All drivers confirmed that they operated their vehicle previously on gasoline. They were then asked to compare the vehicle operation on E20 versus the same vehicle's operation on gasoline. On average, the drivers felt that the vehicles performed equal to or better on E20 as the same vehicle did running on gasoline.



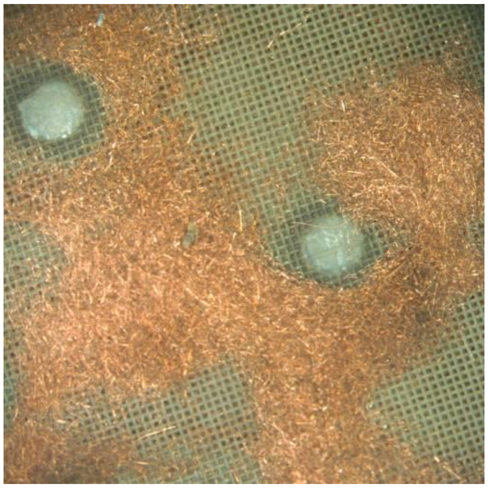
Finally, each operator was asked how satisfied they were running their vehicle on E20. All operators stated that they had a good experience running E20 and that they were comfortable running E20 in their Monroe County vehicle, with 8 out of 10 expressing they would run E20 in their personal vehicle. Surprisingly, the one operator that said he would not use E20 in his personal vehicle experienced only one minor issue and rated the performance of E20 as higher than gasoline, and the unsure operator rated the performance as equivalent to gasoline and reported no issues.

Fuel Pump

Monroe County replaced defective fuel pumps on three sheriff vehicles that were reportedly running E20 fuel. The sheriffs complained of hesitation during acceleration. The old pumps were set aside for autopsy at RIT. The following paragraphs detail the investigation.

The sheriff vehicles were all 2007 Ford Crown Vic police interceptors with conventional gasoline 4.6L, V8 engines rated at 250 HP. The mileage ranged from 57,516 – 79,310 miles at the time when the fuel pumps were replaced.

Upon initial inspection, the fuel filters were contaminated with what appeared to be a metallic substance, or rust. Each component was then carefully separated from the assembly and inspected in detail. Many components had discoloration or tarnish on exposed surfaces that may be considered typical for a fuel pump and system with >50k miles.



Under high powered magnification however, the filter showed what appeared to be copper fibers trapped in the filter mesh. It is likely that the filter was significantly restricted and would reduce flow at WOT causing the performance issues reported by the sheriffs. These fibers were later confirmed to be copper through Energy Dispersive X-Ray Spectrometer.

After inspection of all fuel pump components, it was discovered that the commutator had a grove worn into the copper. The grove was 1.2 mm deep by 4.75 mm wide, resulting in approximately 2.25 grams of copper missing.

Fuel Pump Commutator

All three fuel pump filters had the same appearance. The pump in the pictures came from vehicle 2419. According to Monroe County fueling data, this vehicle had NEVER filled with E20. The first time this vehicle filled with E20 was the day after the pump was replaced.

Vehicle 2428 only filled up with 58.6 gallons of E20 over the course of 10,000 miles, and vehicle 2371 only filled up with 24.2 gallons of E20 over 2500 miles.

Our conclusion is that these pump failures were not related to running E20 fuel.

RIT E20 Lubricity Study

The lubricity of fuel is an indication of the amount of wear that occurs between fuel soaked parts as they come in contact with each other. Low lubricity fuel may cause high wear and scarring and high lubricity fuel may provide reduced wear and longer component life.

Gasoline lubricity is not currently one of the characteristics controlled by industry specification. As of this date, the American Automobile Manufacturers Association (AAMA) has not deemed gasoline lubricity to be of enough significance to include any type of lubricity specification in their AAMA Gasoline Specification. [24] Nor is there a lubricity requirement in ASTM D 4814 Standard Specification for Automotive Spark Ignition Engine Fuel or ASTM D 5798 Standard Specification for Fuel Ethanol (Ed75-Ed85) for Automotive Spark-Ignition Engines.

Very little work on gasoline or ethanol fuel lubricity has been published. This is in large part because fuel lubricity is not thought to have a major impact on fuel system parts in gasoline engines. Lubricity requirements may however become more important with the introduction of "direct injection" gasoline engines which will require high pressure injection pumps. It is therefore important to understand how ethanol fuel lubricity compares with gasoline.

Two test methods have been adopted as standards, namely the Ball on Cylinder Lubricity Evaluator (BOCLE), and the High Frequency Reciprocating Rig (HFRR). [25] The HFRR is commonly used for both the neat fuels and with fuels containing small amounts of lubricity enhancing additives. The first step was to create a HFRR to be used to compare the overall levels of ethanol fuel and gasoline fuel lubricity following a standard protocol.

ASTM D6079-97 Standard Test Method for Evaluating Lubricity of Diesel Fuels was followed to measure the test fuel lubricity using a HFRR. The HFRR is designed to reciprocate a hardened E-52100 non rotating steel ball loaded with 200 grams of mass against a polished annealed E-52100 steel plate. The plate is submerged under a layer of test fuel (approximately ¼ inch depth) at a temperature of 25°C. The ASTM test method requires a 1-mm stroke length oscillating at a frequency of 50 Hz for 75 minutes. After the test, the ball is removed from the apparatus, cleaned, and the resulting wear scar photographed under a microscope using 100 x magnification. Results are recorded and compared. The smaller the wear scar size, the better the lubricity properties of that particular fuel.

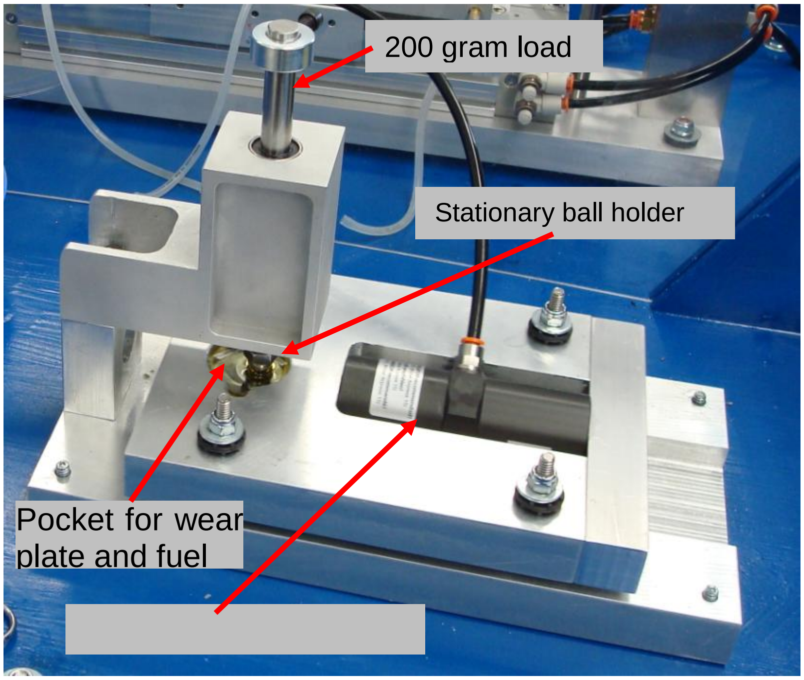
The RIT HFRR design consists of a linear pneumatic vibrator attached to a sliding table that holds the test plate in a shallow bath of fuel. The sliding table is mounted to a stationary base via vibration dampers that allow for motion adjustability. An arm is attached to this same stationary base and contains a linear ball bearing that freely suspends the ball holder in the z-direction above the sliding table while resisting movement in the x and y planes. The freely suspended specimen

[24] Downstream Alternatives, Inc., Lubricity of Reformulated and Oxygenated Gasolines, DAI #970301 March 1997

[25] Margaroni, D., Fuel Lubricity, Industrial Lubrication and Tribology, Volume 50, Number 3, May / June 1998, pp. 108-118

holder weighs 200 grams and provides the required load when lowered onto the plate. Adjustment of the air pressure provides a frequency of 50 Hz, calibrated by using accelerometers. The fixture was further modified by creating a deeper fuel holder (not pictured) to compensate for high volatility and evaporation of gasoline and ethanol fuel. The rig was also completely enclosed in a custom chamber.

Figure 2: RIT High Frequency Reciprocating Rig

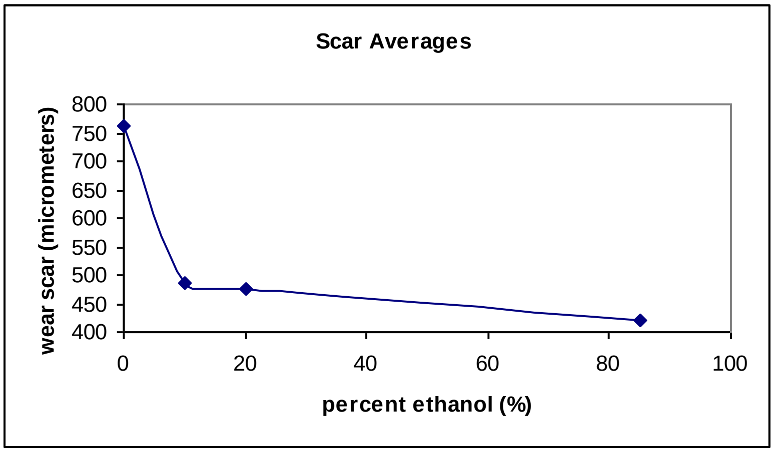


Lubricity Results

The lubricity of various ethanol blends was evaluated. Conventional gasoline was used as the base line fuel for the comparison. This gasoline was purchased from a local Mobil station in Brighton, NY. The E10 fuel was acquired from a Sonoco station located in Henrietta, NY. The E20 and E85 fuels were acquired from Monroe County Fleet facility. Each fuel was run twice and the results were averaged. After the 75 minute test duration, the ball was cleaned removing the remaining gasoline. The resulting scars were measured along the longest and shortest axes (X and Y). Results are shown below.

Fuel	Scar Average (microns)	% change
Gasoline	**761**	**reference**
E10	**485**	**36.3%**
E20	**475**	**37.6%**
E85	**421**	**44.7%**

Figure 3: Representative Wear Scar



The results show a decrease in the wear scar size (lubricity increase) with additions of ethanol.

Lubricity Conclusions

- The HFRR wear test method was adapted and used to successfully measure the wear properties of gasoline and ethanol fuels. The average of a 761 micron scar for gasoline was within the 700 to 900 micron range for scars created on a HFRR with gasoline reported by Wei et al.[26]

- These test results showed a significant improvement in lubricity when adding ethanol. The lubricity improvement was consistent with the findings of Dodge et al. Their results using a ball on cylinder lubricity evaluator showed a wear scar diameter decrease from 600 microns with gasoline to 530 microns using E85.[27]

- It is possible that there may be less wear and long term mechanical benefits from the increased lubricity in ethanol fuels. This benefit however may not be realized until high pressure system such as direct injection engines are more prevalent in the market.

Acknowledgements

The CIMS staff would like to recognize the contributions of our outstanding group of RIT co-op students who supported this project from 2008 to 2010. They are: Patrick Villaume, Matthew Tranter, Ryan Enyeart, Dan Beardslee, Kelsey McConnaghy, Brittany Borella, Christina Smith and Jonathan Seaman.

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[26] Wie, D P, Spikes, H A, Korcek, S, The lubricity of gasoline, Tribology Transactions, October 1999

[27] Dodge, L, Bourn, G, Callahan, T, Gorgan, J, Leone, D, Naegeli, D, Shouse, K, Thring, R, Whitney, K, Development of a Dedicated Ethanol Ultra-Low Emissions Vehicle (ULEV): Final Report, National renewable Energy Laboratory, September 1998.

Appendix A: Fleet Emissions Results

Emissions Results for Vehicle 3562, 1998 Ford F150

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
3562	73860	E00 2007	0.111	0.018	0.912	0.355	553.3			
	80283	E20 2008	0.093	0.021	0.742	0.288	533.6			
Run1		% Change	-16.1%	12.7%	-18.6%	-18.9%	-3.6%			
3562	94435	E00 2009	0.115	0.023	1.178	0.410	521.9	0.095	0.000	0.095
	94503	E20 2009	0.111	0.028	1.093	0.419	524.1	0.085	0.006	0.089
Run2		% Change	-3.8%	20.0%	-7.3%	2.0%	0.4%	-10.5%		-6.3%
		E00 Change	3.8%	27.3%	29.2%	15.5%	-5.7%			
		E20 Change	18.9%	35.5%	47.2%	45.4%	-1.8%			

Emissions Results for Vehicle 3675, 2000 Chevy Impala

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
3675	83030	E00 2007	0.053	0.015	0.859	0.128	446.2			
	89966	E20 2008	0.048	0.015	0.707	0.172	456.5			
Run1		% Change	-9.8%	-1.1%	-17.7%	34.9%	2.3%			
3675	95740	E00 2009	0.069	0.019	1.299	0.110	431.6	0.054	0.000	0.054
	95819	E20 2009	0.053	0.018	0.664	0.157	431.7	0.038	0.004	0.040
Run2		% Change	-22.7%	-5.4%	-48.9%	42.3%	0.0%	-28.5%		-25.4%
		E00 Change	29.9%	27.3%	51.2%	-13.6%	-3.3%			
		E20 Change	11.3%	21.8%	-6.1%	-8.9%	-5.4%			

Emissions Results for Vehicle 4029, 2001 Ford F250

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4029	54499	E00 2007	0.221	0.047	2.534	0.385	792.8			
	57527	E20 2008	0.186	0.046	1.777	0.387	754.6			
Run1		% Change	-15.7%	-1.4%	-29.9%	0.6%	-4.8%			
4029	62903	E00 2009	0.243	0.048	2.793	0.565	827.3	0.201	0.000	0.201
	62971	E20 2009	0.222	0.046	1.838	0.551	836.6	0.182	0.010	0.187
Run2		% Change	-8.8%	-4.8%	-34.2%	-2.5%	1.1%	-9.5%		-7.0%
		E00 Change	9.9%	3.6%	10.2%	46.8%	4.3%			
		E20 Change	19.0%	0.0%	3.4%	42.3%	10.9%			

Emissions Results for Vehicle 4030, 2001 Ford F250

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4030	107611	E00 2007	0.193	0.044	3.032	0.533	854.9			
	116415	E20 2008	0.196	0.048	2.497	0.556	769.7			
Run1		% Change	1.5%	9.9%	-17.6%	4.2%	-10.0%			
4030	130786	E00 2009	0.273	0.058	3.103	0.799	802.4	0.223	0.000	0.223
	130854	E20 2009	0.259	0.060	2.330	0.794	790.6	0.208	0.014	0.215
Run2		% Change	-5.1%	3.4%	-24.9%	-0.5%	-1.5%	-6.9%		-3.7%
		E00 Change	41.6%	32.8%	2.3%	49.8%	-6.1%			
		E20 Change	32.4%	25.0%	-6.7%	43.0%	2.7%			

Emissions Results for Vehicle 4066, 2001 Chevy Silverado

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4066	119776	E00 2007	0.256	0.043	2.675	0.338	649.6			
	131221	E20 2008	0.215	0.039	1.983	0.311	614.5			
Run1		% Change	-15.9%	-9.2%	-25.9%	-8.1%	-5.4%			
4066	147582	E00 2009	0.256	0.042	2.188	0.404	623.4	0.219	0.000	0.219
	147650	E20 2009	0.252	0.052	2.250	0.397	620.0	0.207	0.009	0.212
Run2		% Change	-1.3%	22.8%	2.9%	-1.6%	-0.5%	-5.3%		-3.4%
		E00 Change	-0.1%	-2.3%	-18.2%	19.3%	-4.0%			
		E20 Change	17.3%	32.2%	13.5%	27.8%	0.9%			

Emissions Results for Vehicle 4075, 2001 Chevy Blazer

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4075	48787	E00 2007	0.060	0.021	0.993	0.237	582.1			
	52371	E20 2008	0.052	0.018	0.319	0.305	590.2			
Run1		% Change	-13.0%	-15.6%	-67.8%	28.3%	1.4%			
4075	59717	E00 2009	0.072	0.021	0.634	0.253	559.1	0.054	0.000	0.054
	59785	E20 2009	0.055	0.020	0.317	0.289	545.7	0.038	0.002	0.038
Run2		% Change	-23.4%	-4.8%	-50.1%	14.2%	-2.4%	-30.0%		-28.5%
		E00 Change	19.7%	-1.6%	-36.2%	6.6%	-3.9%			
		E20 Change	5.4%	11.1%	-0.8%	-5.1%	-7.5%			

Emissions Results for Vehicle 4126, 2002 Chevy G3500 Van

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4126	82794	E00 2007	0.323	0.075	1.962	1.427	741.9			
	87670	E20 2008	0.296	0.074	2.016	1.313	725.9			
Run1		% Change	-8.4%	-0.9%	2.8%	-8.0%	-2.2%			
4126	97989	E00 2009	0.335	0.074	2.587	1.400	794.3	0.272	0.000	0.272
	98057	E20 2009	0.287	0.079	1.847	1.380	783.5	0.218	0.017	0.227
Run2		% Change	-14.5%	7.7%	-28.6%	-1.4%	-1.4%	-19.7%		-16.5%
		E00 Change	3.9%	-1.3%	31.9%	-1.9%	7.1%			
		E20 Change	-3.0%	7.2%	-8.4%	5.1%	7.9%			

Emissions Results for Vehicle 4137, 2002 Ford F250

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4137	120818	E00 2007	0.272	0.047	2.097	0.513	839.2			
	123275	E20 2008	0.204	0.036	1.437	0.497	798.5			
Run1		% Change	-24.9%	-23.6%	-31.5%	-3.2%	-4.9%			
4137	130794	E00 2009	0.265	0.043	2.103	0.518	815.3	0.228	0.000	0.228
	130862	E20 2009	0.252	0.050	1.867	0.514	824.3	0.209	0.015	0.217
Run2		% Change	-4.6%	15.5%	-11.2%	-0.7%	1.1%	-8.0%		-4.7%
		E00 Change	-2.7%	-7.9%	0.3%	0.9%	-2.9%			
		E20 Change	23.6%	39.3%	29.9%	3.6%	3.2%			

Emissions Results for Vehicle 4140, 2002 GMC Sierra 1500

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	Calculated EtOH g/mi	Calculated NMOG g/mi
4140	51123	E00 2007	0.183	0.034	1.541	0.382	638.5			
	55304	E20 2008	0.151	0.032	1.237	0.354	595.8			
Run1		% Change	-17.4%	-6.8%	-19.8%	-7.3%	-6.7%			
4140	66446	E00 2009	0.179	0.035	1.674	0.402	631.7	0.150	0.000	0.150
	66514	E20 2009	0.162	0.037	1.295	0.425	624.6	0.130	0.004	0.132
Run2		% Change	-9.6%	5.8%	-22.7%	5.9%	-1.1%	-12.8%		-11.5%
		E00 Change	-2.0%	1.0%	8.6%	5.1%	-1.1%			
		E20 Change	7.3%	14.6%	4.7%	20.2%	4.8%			

Emissions Results for Vehicle 4230, 2004 Ford F250

	Odometer at test start	Test ID	BAG HC gm/mi	BAG CH4 gm/mi	BAG CO gm/mi	BAG NOX gm/mi	BAG CO2 gm/mi	Calculated NMHC g/mi	EtOH g/mi	NMOG g/mi
4230	29738	E00 2007	0.118	0.018	0.824	0.214	740.6			
	36252	E20 2008	0.103	0.020	0.675	0.224	752.3			
Run1		% Change	-12.6%	9.1%	-18.2%	4.6%	1.6%			
4230	53837	E00 2009	0.174	0.033	1.428	0.337	728.5	0.145	0.000	0.145
	53905	E20 2009	0.122	0.028	0.797	0.285	712.5	0.098	0.008	0.102
Run2		% Change	-29.6%	-13.3%	-44.2%	-15.5%	-2.2%	-32.5%		-29.7%
		E00 Change	46.6%	78.2%	73.2%	57.6%	-1.6%			
		E20 Change	18.1%	41.7%	18.2%	27.4%	-5.3%			

Fleet Summary

Fleet Ave	HC	CH4	CO	NOx	CO2	NMHC	EtOH	NMOG
Run 1 Delta	-13.7%	-3.8%	-23.2%	-2.4%	-3.6%			
Run 2 Delta	-10.3%	5.6%	-24.7%	0.3%	-0.6%	-13.8%		-11.0%
E00 change	15.0%	15.7%	15.3%	18.6%	-1.7%			
E20 change	15.0%	22.8%	9.5%	20.1%	1.0%			

Appendix B: E85 Fueling Data

ID	Make	Model	Year	Gas road MPG	EPA MPG†	Gas Gal	Data Pts	Data Date Range	E85 road MPG	EPA E85†	E85 Gal	Data Pts	Data Date Range	Same Org?	On-road Delta
4545	CHEV	Silverado	2007	13.8	15.9	982	48	2/6/08-2/6/09	11.9	12.2	1298	58	2/26/09-2/26/10	YES	-13.77%
4561	CHEV	Silverado	2007	13.7	15.9	649	32	1/15/08-1/15/09	11.9	12.2	931	47	3/6/09-3/6/10	YES	-13.14%
4562	CHEV	Silverado	2007	13.1	15.9	790	37	2/14/08-2/14/09	12.4	12.2	1610	84	3/13/09-3/13/10	YES	-5.34%
4563	CHEV	Silverado	2007	14	15.9	547	23	1/16/08-1/16/09	11.8	12.2	439	22	3/19/09-3/19/10	YES	-15.71%
4568	FORD	Crown Vic	2008	13.5	17.8	366	33	2/14/08-2/14/09	12.7	12.8	692	68	2/26/09-2/26/10	YES	-5.93%
4572	CHEV	Tahoe	2007	12.8	15.9	876	46	2/19/08-2/19/09	10.6	11.5	1000	49	3/12/09-3/12/10	YES	-17.19%
4437	CHEV	Impala	2007	18.6	21.4	637	50	3/7/08-3/7/09	15.5	16.5	773	59	3/17/09-3/17/10	YES	-16.67%
4438	CHEV	Impala	2007	21.1	21.4	347	24	2/14/08-2/14/09	18.6	16.5	409	29	3/23/09-3/23/10	YES	-11.85%
4440	CHEV	Impala	2007	21.8	21.4	798	103	2/11/08-2/11/09	18.2	16.5	929	107	3/2/09-3/2/10	YES	-16.51%
4449	CHEV	Impala	2007	17.4	21.4	350	32	1/24/08-1/24/09	15.1	16.5	405	36	3/9/09-3/9/10	YES	-13.22%
4450	CHEV	Impala	2007	22.4	21.4	391	28	2/12/08-2/12/09	18.5	16.5	402	31	3/5/09-3/5/10	YES	-17.41%
4451	CHEV	Impala	2007	17.7	21.4	700	60	12/11/07-12/11/08	14.2	16.5	858	69	3/5/09-3/5/10	YES	-19.77%
4452	CHEV	Impala	2007	20.1	21.4	670	64	1/7/08-1/7/09	17.6	16.5	808	85	3/6/09-3/6/10	YES	-12.44%
4454	CHEV	Impala	2007	18.2	21.4	722	77	3/5/08-3/5/09	15.7	16.5	713	77	3/19/09-3/19/10	YES	-13.74%
4456	CHEV	Impala	2007	20.8	21.4	538	38	2/7/08-2/7/09	19	16.5	610	42	3/12/09-3/12/10	YES	-8.65%
4458	CHEV	Impala	2007	19.1	21.4	453	36	1/25/08-1/25/09	16.6	16.5	487	41	3/26/09-3/26/10	YES	-13.09%
4465	CHEV	Impala	2007	21.5	21.4	567	48	2/14/08-2/14/09	18.2	16.5	653	52	3/13/09-3/13/10	YES	-15.35%
4466	CHEV	Impala	2007	20.7	21.4	449	37	2/11/08-2/11/09	18	16.5	546	43	3/9/09-3/9/10	YES	-13.04%
4468	CHEV	Impala	2007	18.4	21.4	756	83	2/8/08-2/8/09	16.1	16.5	592	63	3/6/09-3/6/10	YES	-12.50%
4470	CHEV	Uplander	2007	20.9	18.5	648	41	2/6/08-2/6/09	16.3	13.8	675	48	3/19/09-3/19/10	YES	-22.01%
4471	CHEV	Impala	2007	18.8	21.4	684	63	2/11/08-2/11/09	16.8	16.5	747	68	3/4/09-3/4/10	YES	-10.64%
4472	CHEV	Impala	2007	19	21.4	638	50	2/11/08-2/11/09	16.7	16.5	888	78	2/26/09-2/26/10	YES	-12.11%
4477	CHEV	Uplander	2007	16.9	18.5	601	51	10/25/07-10/25/08	13.9	13.8	405	40	3/12/09-3/12/10	YES	-17.75%
4479	CHEV	Uplander	2007	15.5	18.5	358	24	12/20/07-12/20/08	13	13.8	569	43	3/5/09-3/5/10	YES	-16.13%
4483	CHEV	Uplander	2007	19.4	18.5	505	38	2/7/08-2/7/09	16.6	13.8	590	42	3/31/09-3/31/10	YES	-14.43%
4072	FORD	Taurus SE	2001	24.7	19.1	488	43	1/15/08-1/15/09	20.8	14.1	614	57	3/4/09-3/4/10	YES	-15.79%
4088	FORD	Taurus SE	2002	16.4	20.6	229	21	11/29/07-11/29/08	14	14.9	298	28	1/29/09-1/29/10	YES	-14.63%
				Ave 18.16	Ave 19.73	Total 15739	Total 1230		Ave 15.58	Ave 14.98	Total 18941	Total 1466			-14.03%

†EPA vehicle data from www.fueleconomy.gov for the specific vehicle and model year, based on 45% highway driving, 55% city driving, using the 2008 revision calculation method

Appendix C: E20 Fueling Data

ID	Make	Model	Year	Gas MPG	Gas Gal	Pts	Data Date Range	E20 MPG	E20 Gal	Pts	Data Date Range	Same Org?	Delta
4030	FORD	F250	2001	12.6	1256	70	4/2/07-4/2/08	12.6	1061	70	4/18/08-4/18/09	Yes	0.00%
4075	CHEV	TRAILBLAZER	2001	16.1	529	36	3/27/07-3/27/08	16	433	28	5/16/08-5/16/09	YES	-0.62%
4230	FORD	F250	2004	12.2	872	37	4/3/07-4/3/08	12.2	1080	57	4/23/09-4/23/10	Yes	0.00%
3614	FORD	F150	1999	12.8	439	24	10/17/07-10/17/08	12.9	426	26	2/5/09-2/5/10	YES	0.78%
3615	FORD	F150	1999	12.9	460	25	11/14/07-11/14/08	10.4	347	29	1/16/09-1/16/10	YES	-19.38%
3642	FORD	F250	2000	11	704	43	11/29/07-11/29/08	9.7	646	47	2/17/09-2/17/10	YES	-11.82%
3668	CHEV	CG31405	2000	13.1	789	34	11/20/07-11/20/08	12.3	944	41	1/14/09-1/14/10	YES	-6.11%
3669	FORD	F250	2000	11.9	1364	89	11/21/07-11/21/08	10.2	729	50	1/27/09-1/27/10	YES	-14.29%
3671	FORD	F250	2000	12.4	817	41	11/12/07-11/12/08	11.9	1115	55	1/7/09-1/7/10	YES	-4.03%
3683	FORD	TAURUS SE	2000	16.1	243	45	11/28/07-11/28/08	15.3	268	41	1/9/09-1/9/10	YES	-4.97%
4038	FORD	E250	2001	12.1	565	27	11/28/07-11/28/08	12	451	22	2/18/09-2/18/10	YES	-0.83%
4039	FORD	E250	2001	9.9	954	40	11/26/07-11/26/08	9.6	1137	47	12/15/08-12/15/09	YES	-3.03%
4044	FORD	WINDSTAR	2001	17.3	445	24	11/19/07-11/19/08	15.8	392	22	2/24/09-2/24/10	YES	-8.67%
4060	FORD	EXPLORER	2002	15.9	934	56	11/28/07-11/28/08	14.9	696	42	1/3/09-1/3/10	YES	-6.29%
4086	FORD	TAURUS SE	2001	17.5	309	28	12/7/07-12/7/08	17.1	504	59	1/21/09-1/21/09	YES	-2.29%
4102	CHEV	IMPALA	2001	17.5	480	54	11/9/07-11/9/08	17.1	479	49	1/8/09-1/8/10	YES	-2.29%
4127	CHEV	G3500	2002	10.1	991	52	11/26/07-11/26/08	9.7	1102	62	1/12/09-1/9/10	YES	-3.96%
4136	CHEV	SILVERADO 2500	2002	9.1	969	46	10/15/07-10/15/08	8.7	1039	49	1/15/09-1/15/10	YES	-4.40%
4138	FORD	F250	2002	10.8	1053	43	12/15/07-12/15/08	9.7	534	23	1/22/09-1/22/10	YES	-10.19%
4146	CHEV	1500	2003	14.4	853	32	11/15/07-11/15-08	13.3	811	46	1/23/09-1/23/10	YES	-7.64%
4147	CHEV	1500	2003	17.2	862	32	8/15/07-8/15/08	14.4	1034	45	12/26/08-12/26/09	YES	-16.28%
4181	FORD	F250	2003	11.2	1321	97	12/6/07-12/6/08	10.2	1702	89	1/12/09-1/12/10	YES	-8.93%
4182	FORD	F250	2003	12.2	1011	43	12/3/07-12/3/08	11.8	938	39	2/9/09-2/9/10	YES	-3.28%
4196	FORD	EXPLORER	2004	15.9	1037	75	11/29/07-11/29/08	14.7	920	78	1/14/09-1/14/10	YES	-7.55%
4216	CHEV	BLAZER	2004	19	663	46	11/27/07-11/27/08	17.7	702	50	1/22/09-1/22/10	YES	-6.84%
4221	CHEV	IMPALA	2004	23.3	369	29	11/28/07-11/28/08	21.5	428	35	1/6/09-1/6/10	YES	-7.73%
4222	CHEV	IMPALA	2004	25.3	332	23	11/7/07-11/7/08	21.9	405	26	2/6/09-2/6/10	YES	-13.44%
4224	CHEV	IMPALA	2004	24.4	450	33	11/16/07-11/16/08	24.6	412	30	1/5/09-1/5/10	YES	0.82%
4516	JEEP	GRAND CHEROKEE	2007	16.2	938	65	11/29/07-11/29/08	15.6	1087	70	1/7/09-1/7/10	YES	-3.70%
1932	FORD	TAURUS	1998	20.3	392	59	11/30/07-11/30/08	19.1	237	30	1/23/09-1/23/10	YES	-5.91%
4062	CHEV	3500	2001	14.1	1156	58	11/26/07-11/26/08	12.4	561	30	2/19/09-2/19/10	YES	-12.06%
4099	CHEV	BLAZER	2001	16.2	549	37	11/27/07-11/27/08	16.2	492	33	1/13/09-1/13/10	YES	0.00%
4125	CHEV	G3500	2002	8.2	986	60	12/10/07-12/10/08	8.2	822	51	12/30/08-12/30/09	YES	0.00%
4135	CHEV	SILVERADO 2500	2002	11.6	1420	70	11/14/07-11/14/08	11	999	45	1/6/09-1/6/10	YES	-5.17%
4217	CHEV	3500	2004	11.5	1497	62	11/26/07-11/26/08	10.2	1364	71	2/27/09-2/27/10	YES	-11.30%
4232	FORD	F250	2004	11.8	1946	118	12/12/07-12/12/08	12.1	2061	111	12/17/08-12/17/09	YES	2.54%
4235	FORD	EXPLORER	2004	15.3	791	49	11/25/07-11/25/08	14.7	1044	81	1/2/09-1/2/10	YES	-3.92%
4253	FORD	EXPLORER XLT	2005	17.2	883	83	11/30/07-11/30/08	16.5	927	82	12/18/08-12/18/09	YES	-4.07%
4282	CHEV	EXPRESS	2005	10.5	712	37	11/21/07-11/21/08	9.9	578	32	12/22/08-12/22/09	YES	-5.71%
4284	CHEV	EXPRESS	2005	13.1	786	39	11/14/07-11/14/08	12.8	641	30	12/16/08-12/16/09	YES	-2.29%
4286	CHEV	EXPRESS	2005	12.8	1356	71	11/26/07-11/26/08	11.8	1233	59	12/22/08-12/22/09	YES	-7.81%
4290	FORD	F250	2006	11.3	579	36	11/29/07-11/29/08	10.4	536	30	3/11/09-3/11/10	YES	-7.96%
4397	FORD	CROWN VIC	2006	13.2	1004	101	11/29/07-11/29/08	11.4	760	80	12/29/08-12/29/09	YES	-13.64%
4444	CHEV	TRAILBLAZER	2007	17.1	1011	69	11/15/07-11/15/08	15.5	1390	79	1/6/09-1/6/10	YES	-9.36%
4448	CHEV	TRAILBLAZER	2007	15	780	81	12/5/07-12/5/08	14.7	808	84	1/9/09-1/9/10	YES	-2.00%
4564	FORD	E350	2007	12	1080	56	11/16/07-11/16/08	10.9	921	44	1/29/09-1/29/10	YES	-9.17%
4577	FORD	E350	2008	9.9	1040	53	12/10/07-12/10/08	9.5	1385	69	1/5/09-1/5/10	YES	-4.04%
total					39977	2428			38581	2368			-5.93%