ABSTRACT

ROY, BRYAN ERIK. An E85 Ethanol Fuel Impact Study for Wake County, North Carolina; addressing the economical, operational, environmental and social issues. (Under the direction of Richard R. Johnson and Alexander O. Hobbs)

The value of ethanol as an alternative fuel has recently been a highly debated topic. There have been many strong opinions for and against its use expressed by governmental agencies, public interest, and industrial groups. The objective of this study was to determine the impact of using ethanol fuel in the U.S. and particularly Wake County, North Carolina, from an economical, operational, environmental, and social view.

Current corn production and ethanol fermentation methods produce the fuel at a net energy gain in addition to creating valuable co-products such as corn oil or dried distillers grains with solubles (DDGS). North Carolina can currently benefit economically from the ethanol production industry, but not agriculturally until other feedstocks besides corn are utilized. This climate is not good for corn growing, which is why NC imports a large amount each year for animal feed. Since corn is already transported here, using some for ethanol fermentation while still producing high protein DDGS for the hog and poultry industry can be profitable. Wake County has a large flex-fueled vehicle (FFV) population close to 9,000 that can use ethanol as a fuel. This will drive the region's ethanol fuel market in addition to what can be distributed to other close populated centers such as Charlotte, Richmond, and even Washington D.C.

FFVs have the ability to operate on any ethanol blend from 0-85% with no performance differences except for a decrease in fuel economy. The three tested FFVs in this study showed a 24.3% drop in fuel economy when using E85. This amounted to a 0.58 gallon displacement of gasoline when one gallon of E85 was used by Wake County's flex-fueled vehicles. Using E85 can significantly reduce the petroleum import when utilized by every

FFV owner. On-road tests also showed an average reduction of 52% in carbon monoxide emissions when using E85, which can help some counties in North Carolina that have been in danger of being classified as a non-attainment area for carbon monoxide. Other emissions such as nitric oxides and hydrocarbons varied with each vehicle, but showed no significant overall result that would negate the carbon monoxide benefit. Additionally, when accounting for the agricultural production, carbon dioxide levels in the atmosphere will not increase as much with ethanol as when burning gasoline.

In a survey of flex-fueled vehicle owners in Wake County, it was found that only 13% knew that their vehicle could run on a fuel other than gasoline. In a population that indicated they were very concerned with the state of fuel in the U.S., particularly because of the rising costs and the dependence on foreign oil, it was surprising that so many were unaware of their vehicle's capability to use an alternative fuel. However, 93% were willing to buy an alternative fuel and 85% would factor in the type of fuel a vehicle used before buying their next automobile. This indicates that we need more reliable and clear information about alternatives available to consumers. From the benefits found in this impact study, ethanol is concluded to be a viable alternative fuel for this area right now. Efforts should be made in the ethanol industry to increase production and make the alternative available so consumers have a choice and can decide for themselves if ethanol will play a large part in our fuel consumption in the future.

AN E85 ETHANOL FUEL IMPACT STUDY FOR WAKE COUNTY, NORTH CAROLINA; ADDRESSING THE ECONOMICAL, OPERATIONAL, ENVIRONMENTAL AND SOCIAL ISSUES

by
BRYAN ERIK ROY

A thesis submitted to the Graduate Faculty of
North Carolina State University
In partial fulfillment of the
Requirements for the Degree of
Master of Science

MECHANICAL ENGINEERING

Raleigh, NC

2005

APPROVED BY

____
Dr. Herbert M. Eckerlin

____
Dr. Alexander O. Hobbs

____
Dr. Richard R. Johnson, Chair of Advisory Committee

BIOGRAPHY

Bryan Roy received his Bachelors of Science in Mechanical Engineering from Union College in Schenectady, NY in June 2000. He graduated Summa Cum Laude with departmental honors and a minor in environmental studies. He successfully passed the Engineer in Training (EIT) exam in May 2000. Currently, Bryan is enrolled in the Mechanical and Aerospace Department at North Carolina State University and is expected to graduate in December 2005 with a Masters of Science in Mechanical Engineering.

As an undergraduate Bryan worked as an engineering researcher on Composite Material, Heat Transfer, and Autoignition Temperatures of Oxygenated Fuel projects. He also participated in a one year co-op with Plug Power doing fuel cell research for automotive applications. From 2000 – 2002 Bryan served as a Peace Corps Volunteer teaching math and science to middle school students on a small island in Vanuatu, a country in the South Pacific. After returning, he moved to North Carolina in 2003 and began working for the North Carolina Solar Center in October of that year.

During his work at the Solar Center, Bryan has assisted on many alternative energy research projects. He has published the “Evaluation Update of Packaged Solar Domestic Hot Water Systems for North Carolina” in 2004 and provided technical assistance on solar thermal systems to various projects around the state. He has been involved in numerous photovoltaic and wind turbine workshops, demonstrations, and installations throughout North Carolina. Bryan coordinated the North Carolina middle school’s Junior Solar Sprint Program for the 2004-2005 school year and visited many schools to demonstrate alternative fueled vehicles during this time.

Most recently, he maintains the equipment and displays in the Alternative Fueled Vehicle Garage added to the Solar Center’s Facility in 2002. For the past year Bryan has worked with Wake Technical Community College on the E-85 Infrastructure Project focusing primarily on the environmental impact of E85 to North Carolina. With the love and support from his wife, family, and friends, Bryan hopes to continue to working with alternative energy and fuels. Through research, teaching, and demonstration we will find a way to expand alternatives and meet our energy needs for the future.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Ethanol was the fuel of choice for the majority of the first car models as well as an antiknock additive with gasoline. This changed under the influence of Big Oil's cheap petroleum and the discovery of tetraethyl lead as an antiknock additive in the 1920's led us down the road of oil dependence and pollutant gasoline additives that we find ourselves on today. Although the exact future date is debated, the oil supply will eventually run out or reach a point where it costs more to extract the resource than it is worth. Additionally, the burning of petroleum is releasing large amounts of carbon into our atmosphere, carbon that has been stored in our earth for millions of years along with other harmful gases and pollutants. One alternative solution to using petroleum returns us to the fuel for Ford's Model T - Ethanol.

Ethanol as a fuel has recently been the focus of much attention in the government and media with monetary support being proposed for the industry in the current national energy bill. With ethanol becoming a vital part of our energy system there have been many groups and individuals both for and against the expanded use of ethanol as a fuel. U.S. farmers, especially corn growers, and ethanol producers are pushing increased production to provide economic support to their industries. Other groups are promoting ethanol's pollution reduction characteristics, domestic production, and renewable value that sets it apart from petroleum even though it is used in a very similar fashion. Big oil companies, along with some researchers and environmentalists, claim that ethanol production has a net energy loss, pollutes the environment with toxic chemicals, uses a valuable food product, and should not be expanded because enough agricultural crops cannot be grown to supply enough fuel for the U.S.

Realistically, ethanol produced by fermentation will not be able to replace the entire fuel supply in the U.S.. Our society currently uses an excessive amount of fuel, about 175 billion gallons per year, and there is not enough land to grow the feedstocks used to produce ethanol by today's methods. However, replacing the entire oil supply is not the goal of the ethanol industry at the moment. The goal is to reduce the petroleum demand by 5-10% with ethanol using starch based technology. It is when we combine fermentation with other alternative production methods in development that ethanol will make a significant change.

Presently, ethanol as a fuel is not the ‘holy grail’ of alternative fuels that will provide an unlimited energy supply with little or no pollution. Electric vehicles, when charged with renewable resources such as solar or wind, show promise and are zero-emission vehicles. However, battery developments have yet to overcome the limited range capability or the lengthy recharging time. Newly popular hybrid vehicles, combining both gas and electric, have utilized some of the advantages of electric vehicles by providing increased fuel economy but currently still rely partially on nonrenewable petroleum fuel. Hopefully these will continue to evolve and become more like the zero-emission electric vehicles. These future hybrids would have a greater energy storage capacity that can be electrically charged from renewable sources such as solar, while using a renewable fuel such as biodiesel or ethanol. Many are betting on fuel cell cars that only emit water as they combine hydrogen and oxygen, to be the future of transportation. However, years of research and expensive infrastructure changes are required before they become a reality. Additionally, hydrogen, although plentiful on earth, does not occur naturally as a gas by itself and must be created to be used as a fuel. Once created, it can be used in either a fuel cell or a modified internal combustion engine that has drastically improved emissions compared to today’s vehicles.

Current alternative fueled vehicle production is limited to compressed natural gas, biodiesel, and ethanol. With a significant infrastructure already in place, natural gas is available in almost all areas and even right in the homes of those who currently use it for heating. This burns significantly cleaner than gasoline and the technology exists for compressing the gas to store in a vehicle to then burn it in an internal combustion engine. However, natural gas is a petroleum product and will also run out sooner or later, but on a limited scale this is a cleaner alternative than gasoline. Biodiesel has also proven itself as a reliable alternative fuel that burns cleaner than regular diesel. Much like ethanol, biodiesel is made from agricultural products. However biodiesel replaces diesel fuel which is much ‘dirtier’ than gasoline because it releases sulfur dioxide when burned. The environmental benefit of reducing this is very apparent, so biodiesel as an alternative fuel is more accepted. Additionally, the majority of diesel vehicles in the U.S. are commercial trucks and farm equipment, which make up only a small portion of the total fuel consumption. Biodiesel users benefit from both the production and use of the fuel.

That brings us to ethanol, a popular choice for automotive manufacturers that use alternative fueled vehicles for credits to meet the overall fleet fuel economy regulations. However, ethanol as a fuel has yet to become widely accepted. This is due primarily to the largely conflicting reports that exist for ethanol. This project's goals were to evaluate the use of ethanol as a fuel from an economical, operational, environmental, and social view to determine whether it is a viable alternative fuel today, as well as its prospects for the future. In particular, this project focused on the benefits as related to North Carolina and views of the population of Wake County.

Four related, but independent studies were performed to address the concerns mentioned above in the different views. The economical study was done through research of ethanol as a fuel, production methods, alternative feedstocks, and its energy balance. Many studies have previously reported on these issues, which were all reviewed with results summarized in that section. Based on this research, economic conclusions were drawn for North Carolina with the benefits and tax incentives outlined for the development of the local ethanol industry. The operational study looked at E85 usage and fossil fuel savings for the flex-fueled vehicle population in Wake County. Fuel economy tests were conducted and applied to the establishment of an E85 pump ideally located in the county that would displace gasoline normally sold there. On-road emission tests were performed on flex-fueled vehicles comparing gasoline and E85 use for the environmental study. Results of these tests have the potential to show pollution decreases or increases for carbon dioxide, carbon monoxide, nitric oxides, and hydrocarbons. Finally, an awareness survey was conducted by phone to flex-fueled vehicle owners in Wake County to understand the social view of ethanol as a fuel. Questions in the survey addressed the consumer's knowledge of their vehicle, their concerns regarding the current fuel situation, and their willingness to use an alternative fuel.

Assessing the results from each of the four studies that looked at the economical, operational, environmental, and social views of ethanol as a fuel, conclusions were drawn about its potential in Wake County and North Carolina. Although technical in nature, this report aims to present the information for the general public who are ultimately the ones that will decide the fate of ethanol as an alternative fuel.

ETHANOL BACKGROUND INFORMATION AND ECONOMICS

E85 fuel contains 85% ethanol, a renewable energy source that can be made in the U.S. Instead of spending all of our fuel dollars on an irreplaceable resource, we now have an alternative that can spread the wealth to farmers who are struggling to make ends meet. Will it be able to replace fossil fuels? Unfortunately not at the amount we are using them currently. However, displacing 5-10% of the gasoline usage is certainly possible with the ethanol production methods used today. With new advances and different methods, it's feasible that we could see 20% displacement. Although that goal is many years down the road, current increases in production indicate that we are trying to work towards that. The bottom line is whether ethanol is worth it for the producers and consumers; what are the economic benefits today and what is in the forecast for tomorrow?

To understand this issue both nationally and locally, we must first understand the background and history of ethanol. The following sections will provide that information pertaining to the basics of ethanol and its common production method. The issue of energy balance will be addressed along with a look at alternative production methods and feed stocks. Ethanol fuel potential for the US and North Carolina will be explored as well as the economic benefits associated with that potential. Tax incentives for both producers and blenders will also be examined for their economic contribution to developing the ethanol market.

History

Ethanol has been around for hundreds of years, as a beverage and energy source. As a fuel it was used in some of the first engines and cars. Without the readily available fossil fuel resources our society could have easily developed into an ethanol driven culture. Instead, we rely on the inevitable decline in supply and increase in cost of the remaining oil that exists in places like the Middle East, and must find alternatives for our fuel greedy automobile society. Ethanol is one fuel alternative that we can expand to use in more vehicles, while continuing to use it as a beverage, disinfecting agent, preservative, or solvent.

Ethanol is an alcohol naturally formed by the fermentation of sugars by yeast. Sugars are formed by green plants that use photosynthesis to change carbon dioxide and water into sugar (glucose: $C_6H_{12}O_6$) and oxygen. This process actually removes carbon from the atmosphere, one of the concerns associated with global warming. Therefore, even though combusting ethanol produces carbon dioxide, the overall carbon level in the atmosphere will not increase. To store the glucose for growth and reproduction, the plant converts the sugars to starch ($C_6H_{10}O_5$). Some of the most starch rich plants, corn (70% of the dry weight) and potatoes (75% of the dry weight), hold the greatest yield per acre potential for ethanol production.

Producing ethanol in the simplest method reverses the process done by the plants to make the starch. Combining starch and water with an enzyme catalyst will change it back into glucose. Yeast catalyst, a living organism that will digest sugars, when added to the glucose will produce ethanol and carbon dioxide. At this point the ethanol is highly dilute and must be distilled to evaporate the water. This process can create 190 proof ethanol, or 95% ethanol by volume. At this point the ethanol and water form an azeotrope, which will not separate any further by any conventional heating method. Therefore, techniques such as the adsorption of water, distillation with a co-solvent such as cyclohexane, or separation by molecular sieve technology is required [1].

Industrial production

At the industrial level, production facilities use either a wet or dry milling process to produce ethanol. In the wet milling process shown in Figure 1, the corn is soaked for 30-50 hours at 120 - 130°F in a dilute sulfur dioxide solution. Soluble nutrients absorbed in the water can be used to produce condensed corn fermented extractives, a byproduct formed when this liquid is evaporated to concentrate the nutrients. Also removed during the soaking is the corn germ that is further processed to make corn oil or corn germ meal feed. After soaking, the corn kernels pass through a screen to remove the bran which is combined with other co-products' streams to produce a corn gluten feed byproduct. A starch and gluten slurry emerges from the screening process and is sent to centrifugal separators separating the lighter gluten protein from the heavier starch. This gluten protein can then be concentrated and dried to form corn gluten meal, a 60% protein feed. Finally, the starch can be used to make ethanol, or even washed and dried to market to the food, paper, and textile industries. Overall, 25-30% of the corn processed goes to co-products for the feed industry, while the remaining starch can be used for ethanol through fermentation by yeast then distillation [2].

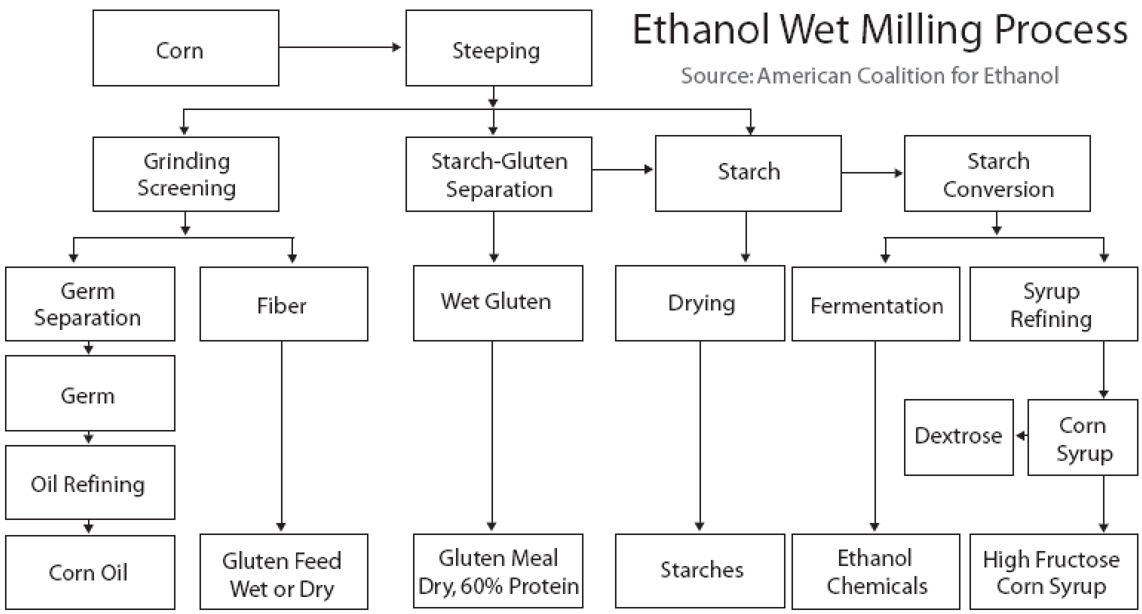


Figure 1: Flow Diagram for the wet milling production of ethanol [3]

The dry milling process, shown in Figure 2, is the more commonly used production method for making ethanol. In this process the incoming grain is screened for the removal of stalks and foreign material and ground by a hammer or roller mill to the consistency of coarse flour. It is then mixed with water in the slurry tank, partially sterilized at 200+ ^{o}F / 10-40 psig, and held at an elevated temperature (180 – 195 ^{o}F) for 4 to 8 hours. A liquefaction process follows next where alpha amylase enzymes are added to break the starch polymer into short sections followed by a saccharification phase when the enzyme gluco amylase is added. This creates a sugary mash that is pumped into the fermentation tanks where yeast converts the sugars to carbon dioxide and ethanol. When complete the mixture now contains dilute ethanol and non-fermentable components. The distillation process then separates the water, ethanol, and whole stillage. The majority of the water can be recycled back to the slurry tank, while the 95% ethanol must be purified further to reach 100% ethanol. For fuel usage this must now be denatured with 5% gasoline otherwise the plant would need a liquor license. The non-fermentable compounds separated in the distillation system can further be processed in centrifuge to be sold as wet distillers grains or dried more to sell as dried distillers grains with solubles or DDGS, which is used as a high protein animal feed. On average, for a 56 pound bushel of 15% moisture corn, 36 pounds of sugar are extracted producing 17.6 pounds of ethanol (2.6 gallons) with 17 pounds of DDGS [4].

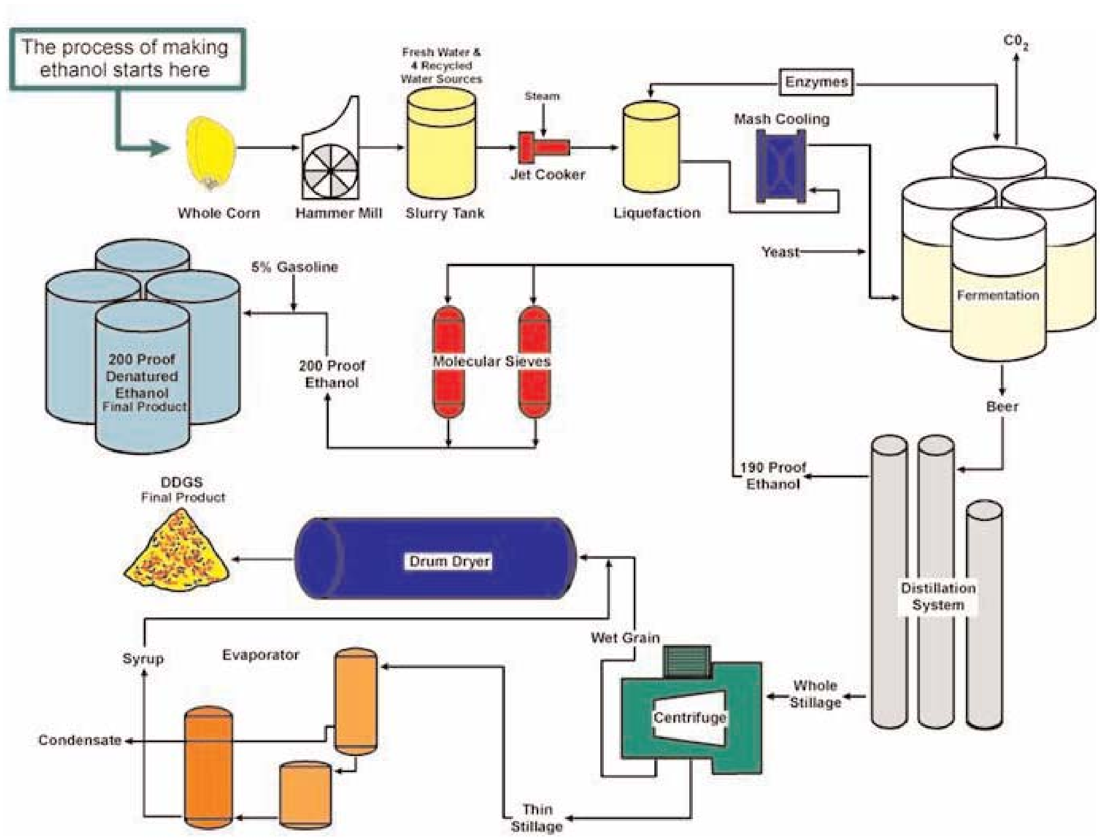


Figure 2: Flow diagram for the dry milling production of ethanol [5]

During the fermentation stage for both the wet and dry milling processes a significant amount of carbon dioxide is released by the yeasts as they convert the sugars to alcohol. Discharged to the environment this gas, although not currently regulated, is a greenhouse gas contributing to global warming. Luckily, fermentation is a very slow and controlled process that allows the carbon dioxide to be collected. This can be purified and sold as another co-product of ethanol production.

Alternative production methods and feedstocks

The majority of ethanol production today uses corn as a feedstock. Since ethanol is made from sugars, many plants can be used as a feedstock. Milo (sorghum), wheat, oats, barley, rye, rice, and whey are other crops that can also be used to make ethanol. These don't contain as much starch and sugars as corn, but their use continues to take advantage of the dried distiller grain co-product to lower the cost of the ethanol fuel. Of these, researchers are particularly interested in developing production with a hulless barley that will provide a better final grain product because the hull (high fiber and not suitable for animal feed) can be easily removed as it separates from the plant near harvest time. This is especially attractive to the east coast were barley grows better than corn and for the production plants because barley is cheaper than corn on a per bushel basis. Other high starch or sugar volume plants that have been considered as good feed stocks include potatoes, sweet potatoes, sugar beets, molasses, or sugar cane. Most of these can produce two to three times more starch per acre than corn, but they are not used because of either their high crop production costs, value as a food product, or loss of additional co-products. For example, sugar cane can produce a significantly higher yield per acre at a lower cost and can be simply squeezed for their juices that are ready for fermentation, eliminating a step in the ethanol production. However, the stillage from the plants can not be used as an animal feed and thus disposal becomes an issue [6].

The answer to solving sugar cane's stillage issue and the future of ethanol production may lie with an alternative production method of ethanol that converts cellulosic biomass to ethanol. Research continues to modify the process to make it more efficient and less costly, but the basic production principals have been developed and some companies have already started building plants to produce ethanol in this manner. The cellulosic biomass uses the entire plant that is grown and not just the fruit, utilizing more plant material per acre, most of which has no other usefulness or value in the agricultural industry. This feedstock must first be treated with dilute sulfuric acid at high temperatures for a very short time to free hemi-cellulose sugars and other compounds from the biomass. After treatment with excess lime and ion exchange to remove compounds harmful to the fermentation organism, some of the liquid portion of the hydrolysis stream is split off to enzyme production. Simultaneous saccharification and co-fermentation of the slurry is then completed in a series of continuous anaerobic fermentation trains. This creates a beer of 4-5% ethanol that must be distilled to separate the water and residual solids, and then purified to make ethanol [7].

Another alternative method of ethanol production is through chemical pathways. The catalytic hydration of ethylene to produce ethanol from synthetic gas derived from coal has been proven, but only used for ethanol as a solvent or chemical synthesis. This method is significantly more expensive than the previous two production methods described above, making it unlikely to become the dominant pathway for fuel ethanol production. However, this creates an option to make ethanol from any biomass that can be gasified [8].

Ethanol production energy balance

Another issue of concern that has been raised about ethanol is the overall energy balance of the production methods. Some have claimed that ethanol production actually uses more energy than can be gained from burning ethanol as a fuel, however this has been proven incorrect in many different studies. Table 1 shows the numerous studies performed on this issue with their net energy value for ethanol ranging from a negative energy loss of 33,500 Btu/gal to positive energy gain of 30,589 Btu/gal.

In the most recent Shapouri, Duffield and Wang's 2002 study, the estimated net energy value of corn ethanol was calculated at a gain of 21,105 Btu/gal. This is assuming that the fertilizers are produced by modern processing plants, corn is converted in modern processing facilities, farmers achieve normal corn yields, and energy credits are allocated to co-products. Other previous studies may not have taken into account today's higher corn yields, lower energy use per unit of output in the fertilizer industry, and advances in fuel conversion technologies [9]. The most significant difference among the various studies is the energy for the ethanol conversion process. Pimentel's research considerably overestimates this energy requirement resulting in a net energy loss. A state-of-the-art ethanol plant in Nebraska built in 2004 has been reporting energy uses of 31,000 Btu/gal [10], which is even lower than what was used in the most recent study by the USDA. This value would produce a net energy value near 40,000 Btu/gal. This net energy gain will only increase as better technology is available. However, even factoring in older ethanol producing plants, overall ethanol production is a positive net energy value source of fuel for vehicles.

Table 1: Energy Input assumptions and results for corn-ethanol production studies [9]

Study/year	Corn Yield	Nitrogen fertilizer application rate	Nitrogen fertilizer production	Corn ethanol conversion rate	Ethanol conversion process	Total[1] energy use	Coproducts[1] energy credits	Net[1] energy value
	Bu/acre	*lb/acre*	*Btu/acre*	*gal/bu*	*Btu/gal*	*Btu/gal*	*Btu/gal*	*Btu/gal*
Pimentel (1991)	110	136	37,551	2.50	73,687	131,017(LHV)	21,500	-33,517
Pimentel (2001)	127	129	33,547	2.50	75,118	131,062(LHV)	21,500	-33,562
Keeney and DeLuca (1992)	119	135	37,958	2.56	48,470	91,196(LHV)	8,078	-8,438
Marland and Turhollow (1990)	119	127	31,135	2.50	50,105	73,934(HHV)	8,127	18,154
Lorenz and Morris (1995)	120	123	27,605	2.55	53,956	81,090(HHV)	27,579	30,589
Ho (1989)	90	NR	NR	NR	57,000	90,000(LHV)	10,500	-4,000
Wang et al. (1999)	125	131	21,092	2.55	40,850	68,450(LHV)	14,950	22,500
Agri. And Agri-food Canada (1999)	116	125	NR	2.69	50,415	68,450(LHV)	14,055	29,826
Shapouri et al, (1995)	122	125	22,159	2.53	53,277	82,824(HHV)	15,056	16,193
Shapouri, Duffield and Wang (2002)	125	129	18,392	2.66	51,779	77,228(HHV)	14,372	21,105
Average	117	129	28,680	2.56	55,470	89,525	15,572	5,885

NR: Not Reported
LHV: Low heat value = 76,000 Btu per gallon of ethanol. Keeney and DeLuca used 74,680 Btu per gallon of ethanol.
HHV: High heat value = 83,961 Btu per gallon of ethanol. Lorenz and Morris used 84,100 Btu per gallon of ethanol.
[1]Midpoint or average is used when studies report a range of values

Economic potential for ethanol in the US and North Carolina

The economic potential for the ethanol fuel industry in the U.S. is extremely high, especially with the rising cost and concerns of fossil fuels. With steady increases in the variety of automobile models over the last few years, over 4 million flex-fueled vehicles are now on the roads. The current limiting factor for ethanol is fuel availability. Ethanol production has continued to gradually increase over the last decade with many new plants being constructed and proposed. Newly advanced and larger capacity production facilities will help to lower the price of E85 as the gasoline prices are now reaching all-time highs. Corn production, the primary feed stock used for ethanol production, continues to have record years with larger volumes and greater per acre yields. Only about 5% of the annual national corn production has been used for ethanol production over the past few years, and some anticipate this number growing to 10%. With the dry milling systems being used that produce DDGS as a co-product, 30% of that product is recovered for feed, which would only reduce the available corn feed by 7%. Using modern farming technologies this percentage increase is already being accomplished. With the prospect of selling corn as a fuel feedstock, other less profitable crops may be replaced by corn. This is not the ideal situation because needed food crops should never be sacrificed for fuel crops, but additional farmland is still available in the US and other historical cash crops are not as in demand as they once were.

This is especially true in North Carolina where the tobacco farmers are no longer finding a profitable market for their crops. Unfortunately, the soil in this area is not ideal for corn production, but other usable feed stocks mentioned previously do show potential. Sweet potatoes are one of these crops that fair well in the North Carolina climate. Recent research has been done to develop an industrial grade high yield sweet potato that would be high in starch and ideal for ethanol production. Issues with production costs, storage, processing, and use of the solid residual co-product must be further investigated before this becomes a viable alternative feed stock. Currently that leaves the farmers out of the potential for economic gain, but from a producers perspective North Carolina may be an ideal location. With a significant portion of the corn feed being imported to this state, using only a fraction of that supply and providing a quality dried distillers grain co-product to the immediate hog and poultry industry would equate to a lower feed stock price which primarily drives the cost of ethanol. With relatively close large population areas from the Triangle up through Virginia to Washington, a significant number of flex-fueled vehicles could easily drive a large E85 fuel demand. With a large amount of corn all ready being shipped to this area, ethanol production in this state would reduce the transportation costs of the ethanol fuel currently coming from production plants in the Midwest.

Economically, ethanol producers have a lot to gain by converting corn to ethanol with the high price value increase between the two. With an estimated 2005 average bushel of corn costing about $1.75 [11], it's ethanol equivalent of 2.6 gallons at the $1.60 terminal average [12] for 2004 comes out to be $4.16 or more than double the investment cost. Adding the 17 pounds of the DDGS co-product at $115/ton to the profit adds $0.98 [13], because even though it is only 30% of the initial feed stock volume, the dried distiller's grains are more valuable for their high protein. Current production costs for ethanol are estimated at $0.76 per gallon, which calculates to provide a profit of $0.54 per gallon of ethanol produced. A medium sized ethanol plant would have the capacity of about 30 million gallons per year producing a profit of $16.2M. Thus, a start-up cost of around $100M could be paid off in just over 6 years at these price levels which shows the ethanol fuel industry being a good investment.

In addition to product value increase for a profit, many federal and state tax incentives are available for ethanol. Unfortunately, the state of North Carolina has not established any of these incentives, but federally there are some available to E85 blenders. These can be utilized by the ethanol producers by establishing the ability to blend the fuel, or indirectly seen through blenders buying the ethanol above the market price knowing that they will get the tax incentive. Previous to this year, these incentives included a federal excise tax exemption and a blender's income tax credit. It was found that the exemption was exploited by some oil companies using minimal ethanol content while the income tax credit was not utilized because small blenders would drop below the alternative minimum tax requirement and not receive the full credit. The American Jobs Creation Act of 2004 created the Volumetric Ethanol Tax Credit (VEETC) to eliminate the fraud associated with the federal excise tax exemption and make it easier to use the blender's credit [14]. Under this bill, all ethanol producers and blenders must register with the IRS and pay the 18.4 cents excise tax on fuels. This allows the tracking of the progress and alternative fuel impact on the US while ensuring that the Highway Trust Fund that collects the excise tax is not depleted of funds through fraudulent exemptions. Valid ethanol blenders will then be eligible for the VEETC on any blend of ethanol and will no longer be restricted by the alternative minimum tax so every cent of the credit will be paid. That credit equates to 51 cents for each gallon of ethanol blended with gasoline. An E10 blend would refund 5.1 cents per gallon, while E85 would refund 43.35 cents per gallon. Even a 1% blend of ethanol with gasoline would provide a .51 cent per gallon refund encouraging more to use ethanol instead of other octane boosting additives.

Summary

Ethanol fuel production is expanding in the U.S. because the market is growing and the technology to produce the product is advancing. Today's farming and ethanol conversion process techniques have increased the net energy gain for producing the alternative fuel and the current cost levels show an economic gain. Using current methods for wet or dry milling production ethanol will not be able to replace fossil fuels, but will continue to account for an even greater portion of the total fuel use for the next few years. Four million flex-fueled vehicles in the US have the potential to use 2 billion gallons of ethanol each year, while using 5% ethanol in the 120 billion gallons of gasoline used each year would add an additional 6 billion gallons of ethanol. In 2004, only 3.4 billion gallons of ethanol were produced, so new plants should not expect to run out of demand any time soon, especially with expanded ethanol use proposed in both the house and senate energy bills.

When production techniques for making ethanol from cellulose are developed that can produce the product at competitive costs, an entirely new outlook on ethanol potential will be established. Utilizing other feed stocks will also expand the industry and give farmers in areas other than the mid-west an opportunity to benefit from ethanol. For North Carolina this will most likely involve producing ethanol from sweet potatoes or hulless barley, two alternatives that will most likely be economically viable very soon. Even today, however, an ethanol production plant in NC can be economically feasible because of the current poultry and hog industries that would provide an excellent market for the dried distiller's grains co-product. Factor in the current ethanol demand provided by North Carolina's state fleet of flex-fueled vehicles (largest in the U.S.) with the potential market from the Triangle region to Washington, and ethanol production is a good economic investment. Additional tax incentives can make the prospect even more inviting. Therefore, this is the time and place to join the growing ethanol industry and profit from the investment into an alternative fuel.

WAKE COUNTY E85 USAGE AND FOSSIL FUEL SAVINGS STUDY

Using E85 as a fuel to replace gasoline in automobiles will reduce dependence on a foreign non-renewable resource. The majority of current ethanol production is made from domestic corn plantations, mostly in the Mid-West. As an alternative fuel, ethanol is blended with 15% gasoline and sold as E85, which can be used in flex-fueled vehicles. By utilizing this fuel, the demand for imported oil is reduced. The following sections explain how significant this fossil fuel reduction will be in Wake County from a single E85 filling station. This is done by analyzing the flex-fueled vehicle population with fuel economy performances of these vehicles using E85 instead of gasoline.

Procedure

Flex-fueled vehicles can operate on gasoline, E85, or a combination of the two that contains anywhere from 0-85% ethanol. The major change in these vehicles is the addition of an oxygen sensor in the fuel line to detect the ethanol to gasoline ratio (ethanol has significantly more oxygen) so that the fuel injection and engine timing can be adjusted to burn most effectively with the fuel in the tank. Ethanol is an alcohol, which is corrosive, so other parts in the fuel system are upgraded to handle it, including usually a stainless steel fuel tank and Teflon-lined fuel hoses [15]. There are over 4 million flex-fueled vehicles in the U.S. today, the majority manufactured by GM, Ford, and Chrysler at little or no extra cost to consumers. A listing of flex-fueled vehicles along with VIN number identification patterns to verify a vehicle can use E85 is found in Appendix A.

Using this information, the NC Department of Air Quality was able to supply a listing of Wake County flex-fueled vehicle owners. Unfortunately, there is no specific known VIN number information on Isuzu or Mercedes Benz flex-fueled vehicles so those owners were not identified in this study. No Mercury Mountaineer or Sable flex-fueled vehicles were found in the list which could be due to the fact that only a limited number of these vehicles can run on E85, or their VIN number identifying characters were not used in the search.

The original Wake County flex-fueled vehicle list contained 9,404 entries with VIN numbers with corresponding vehicle make, model and year as well as the owner’s name and address. Reviewing the list, it was found that some entries were from other states and cites outside of

Wake County. Also included on the list were 1991-1995 Chevrolet Silverados that use the same VIN number combinations as their newer flex-fueled vehicle models. After taking these vehicles out, the modified list now contained 8,847 flex-fueled vehicles in Wake County. Visually inspecting the names, 6,423 (73%) vehicles had private owners, while 2,424 (27%) were commercially owned.

As a fuel, a gallon of ethanol contains less energy than a gallon of gasoline. In addition, flex-fueled vehicles are not optimized to run on ethanol, because the vehicle must have the capability to run on any mixture of E85 or gasoline. These two facts mean that the fuel economy of a flex-fueled vehicle running on E85 will differ from the same vehicle running on gasoline. To experimentally determine the loss in fuel economy, a test was performed on three different flex-fueled vehicles that ran on an identical road course with both E85 and gasoline.

Three different size flex-fueled vehicles were chosen to represent the three different vehicle types available to run on E85; a car, minivan, and sport utility vehicle. All vehicles were state-owned allowing use of the fuel at the state E85 pumps and each came from a different manufacturer, representing the most popular used flex-fueled vehicles in their class. These are shown in Figure 3. The car was a 2004 Ford Taurus with about 30,000 miles. It's first eight flex-fueled VIN numbers were 1**FA**FP52**2.** This vehicle was a temporary loan vehicle from the state motor fleet that was filled with E85 from the state pumps when used locally. The minivan was a 2005 Dodge Caravan with about 12,000 miles. It's first eight flex-fueled VIN numbers were 1**D4**GP25**E.** This vehicle was also a temporary loan vehicle from the state motor fleet that was filled with E85 from the state pumps when used locally. The sport utility vehicle was a 2004 Chevrolet Tahoe with about 11,000 miles. It's first eight flex-fueled VIN numbers were 1**GN**EK13**Z.** This vehicle was permanently assigned to the NCSU Cooperative Extension Service, who graciously allowed it to be used for testing. That department was unaware that the vehicle was flex-fueled and most likely had never used E85 in it previous to testing. More vehicle specifications can be found in Appendix B.

Ford Taurus

Dodge Caravan

Chevrolet Tahoe

Figure 3: Three flex-fueled vehicles used in testing

The testing route for the experiment was chosen to easily accommodate starting and finishing at the NC Solar Center's AFV garage and provide a typical mix of driving speeds and conditions. The entire route distance was 12.1 miles with an average driving time of 25 minutes. It included 4 miles (33%) of 60 mph highway driving with the remaining part city driving with potential stops at lights for 3.7 miles (31%) at 45 mph and 4.4 miles (36%) at 35 mph or less. There were 25 potential stopping points, although on average only 12 stops were made on each run. At two stop signs, near the beginning at the Varsity/Western intersection and near the end at the Ashe/Western intersection, hard accelerations from 0 to 45 mph were done to represent an aggressive driving situation that could occur on such a trip. All other accelerations were done at normal rates. Figure 4 shows a reduced image of the testing route, however more route details with road configurations, mileages, and stops can be found in Appendix C.

To ensure the fuel content of each tank on the testing vehicles, the fuel was drained to a minimum before filling with the desired testing fuel. Siphoning the fuel was not possible due to a grate in the fuel filling line to prevent foreign objects from entering the tank and disconnecting the fuel line required special expertise and approval, so each vehicle was run low on fuel through driving.

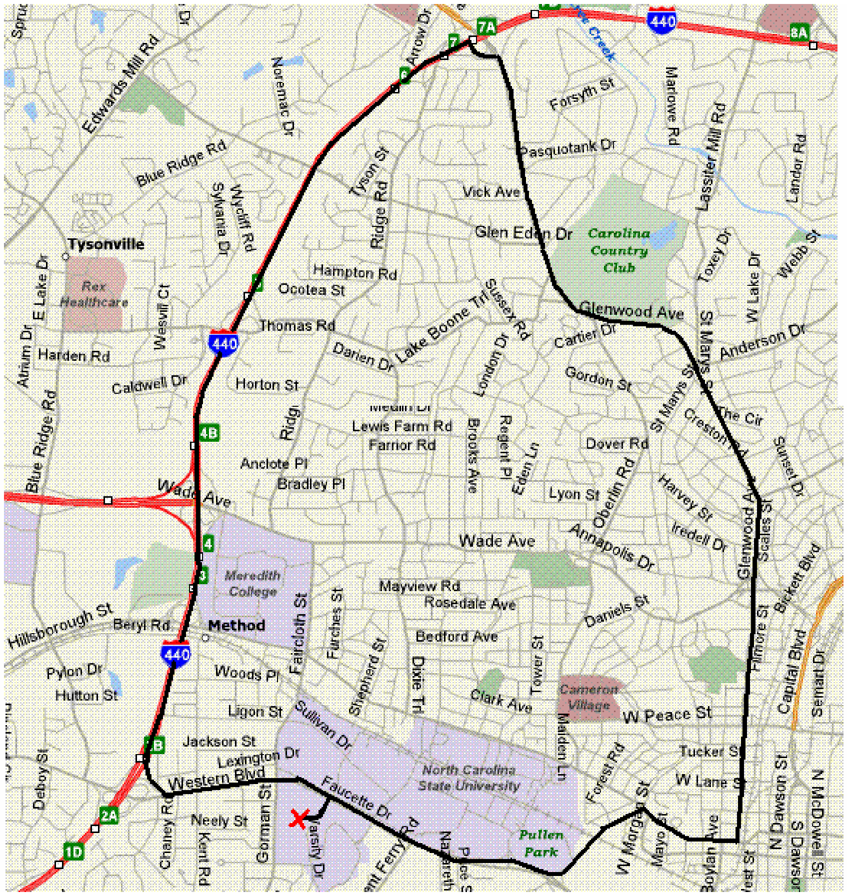


Figure 4: Testing route for fuel economy experiment

Being temporary loan vehicles coming from a location with E85, both the Taurus and Caravan most likely contained a mix of ethanol in their fuel tanks. These vehicles were driven approximately 50 miles beyond when the low gas light lit (manual reports that this indicates 3 gallons or less of gas remaining), then filling with E85 at the state fuel pumps to begin the testing. The Taurus (18 gallon tank) needed 16.5 gallons and the Caravan (20 gallon tank) needed 16.8 gallons. Although the state fuel stations are older (not digital) and may not be as accurate, these numbers indicate that some fuel remained in the tanks and results could be subject to some variance depending on if that remaining fuel was E85 (assumed) or gasoline. These vehicles were then run on the route, making the previously indicated stops and accelerations, until the vehicle sputtered and stalled from the lack of fuel. They were then filled with gasoline from a portable container and driven to a fueling station on Western Boulevard to be topped off and started on the second fuel economy testing with gasoline.

The Tahoe was loaned from a NCSU department which was unaware of it's ability to run on E85 and indicated that it had always been filled with gasoline. With limited loan time and an initial full tank, it was assumed that the fuel in the tank was gasoline, and the vehicle was topped off at the Western Boulevard fueling station to begin the fuel economy testing with gasoline first. Since permission was not granted to fill a portable fuel container with E85, a minimal amount (1-1.5 gallons) of gasoline was used to get the vehicle started after running it out of fuel. All three vehicles took enough added fuel to create some tank pressure (1-2 gallons) and 5-10 attempts to start after running dry of fuel. They would also sputter and be slow to respond at first, but after a few hard accelerations the vehicles would behave normally. Because the E85 fuel was used second in the Tahoe, some gasoline remained in the tank from starting it again after running out of gas. The state's pump indicated that 25.3 gallons of E85 was used to fill the 26 gallon tank, which means at most only 1 to 1.5 gallons (to include all fuel lines) of gasoline remained in the vehicle. This still must be considered in the final calculations.

Results

An analysis of the Wake County flex-fueled vehicle list was performed to determine the highest concentration of vehicles by town and vehicle type, as well as identifying significant fleets in the county. This information was then used in accessing the fuel usage as well as helping to determine possible locations for E85 stations. Numerical information for all the Wake County flex-fueled vehicle statistics can be found in Appendix D. Figure 5 charts the vehicles by city address, showing that Raleigh has an overwhelming number as compared to the other towns. This chart also color codes the vehicles by private or commercial ownership. However, calculating a ratio of the number of flex-fueled vehicles to population and graphing that as in Figure 6, it can be shown that no particular town has a significantly larger ratio than the others. Overall for Wake County, the ratio is 0.0124, which equates to one flex-fueled vehicle for every 80 people.

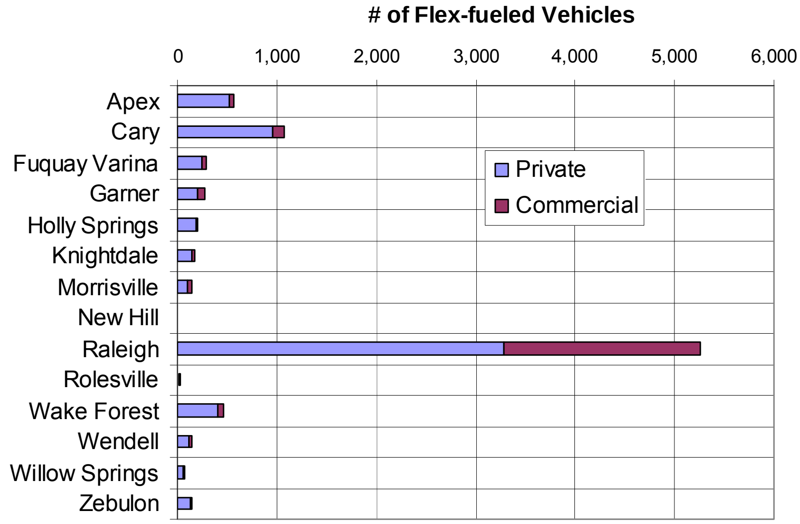


Figure 5: Wake County flex-fueled vehicle distribution by town

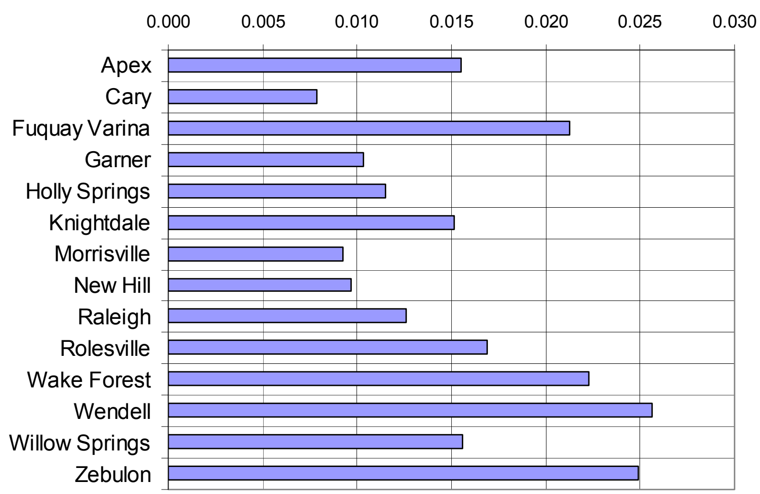


Figure 6: Wake County towns' flex-fueled vehicle to population ratio

In regards to the distribution of Wake County flex-fueled vehicles by vehicle type, Figure 7 shows that the majority of these owners have big vehicles. The sport utility vehicles, Chevrolet's Tahoe and Suburban, Ford's Explorer, and GMC's Yukon, account for 57% of the FFVs in Wake County. This does not represent the overall vehicle type distribution for any fuel, since the majority of the best-selling cars are not flex-fueled, and even most car models that are available in flex-fuel only have that as an option rather than standard equipment as in most SUVs. However, this does indicate the popularity of these vehicle models from the FFV choices, and performance improvements of flex-fueled vehicles should focus on the larger sport utility vehicle engines. It is also apparent that flex-fueled cars sales are driven by fleets, while the vans and SUVs are being sold more to the private owners.

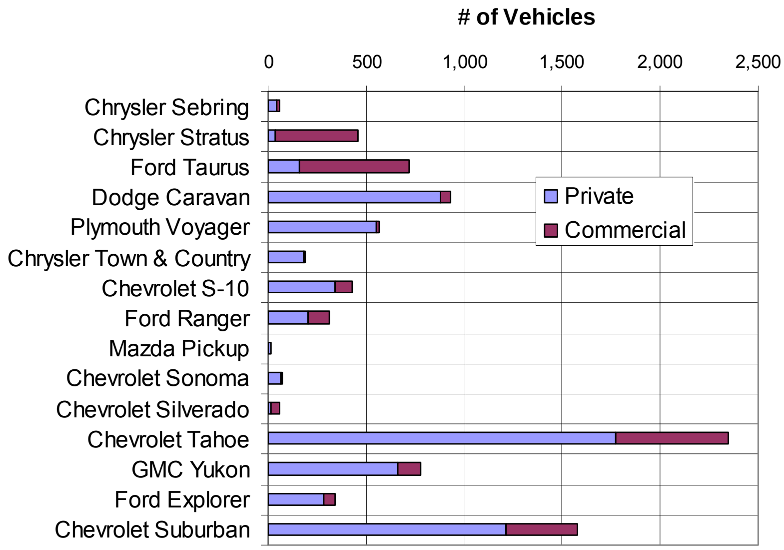


Figure 7: Wake County flex-fueled vehicle distribution by town

A list of significant fleets in Wake County can also be found in Appendix D. This is helpful in identifying filling locations that could be easily accessible to a fleet of flex-fueled vehicles. Aside from the fleets that are located at the state's two E85 filling stations, the largest fleets are those of rental car companies near the RDU airport and North Carolina State University. Rental car companies will fill cars at their own station if they are returned empty, however most encourage their costumers to fill them before returning. Locating an E85 station near the rental offices and arranging with the companies to somehow notify their costumers about this alternative fueling option would be a good strategy for both selling E85 and raising the awareness level of the many costumers that use rental cars. Another good location would be near NCSU or any major universities to utilize their fleets as well as the student population. Traditionally colleges and universities are more progressive in trying new alternatives and being conscious about the environment, so this would be an excellent chance to involve both fleet and private vehicles.

The fuel economy testing provided an identical driving route and style resulting in a valid comparison between gasoline and ethanol. On gasoline, the Ford Taurus ran out of gas at 411 miles while on E85 it ran out at 300 miles. This calculated to be a 27.0% fuel economy drop with ethanol, with a worse case scenario of a 30.2% drop if all of the fuel remaining in the tank when filling up with E85 was gasoline. The Dodge Caravan showed the least fuel economy drop at 17.6% by going 421 miles on gasoline and 346 miles on E85. Again, this percentage could be as high as 22.0% if 3.5 gallons of gasoline were remaining in the tank when filling with E85. This value appears high due to the premature low gas light, which came on 100 miles before the vehicle actually ran out of fuel. This was not known in the beginning when the goal was to run the vehicle out of fuel to fill with E85 and only 50 miles were driven after the light had lit. A 23.7% fuel economy drop was calculated for the Chevrolet Tahoe that went 404 miles and 307 miles on gasoline and E85 respectively. Knowing that in fact there was 1 to 1.5 gallons of extra gas mixed in with the E85, this drop could rise to 25.0%. All fuel economy calculations can be found in Appendix E, while Figure 8 shows the percentage of fuel economy loss by using E85 in the tests along with the calculated average of 24.3% for all three vehicles.

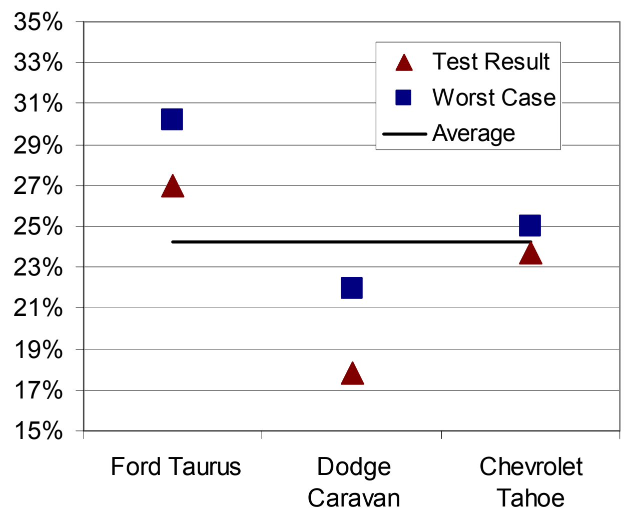


Figure 8: E85 fuel economy loss for the three tested FFVs

The test results were compared with the fuel economy estimates based on results of tests required by the U.S. Environmental Protection Agency and published on a website supported by the U.S. Department of Energy [16]. They list mpg estimates for all vehicles, including flex-fueled vehicles which have listings for both gasoline and E85 on highway and city driving. To calculate the overall mpg in comparison, a 0.33 highway factor and 0.67 city factor was used to simulate the driving conditions used in the study. Figure 9 charts the tested mpg for all three flex-fueled vehicles on gasoline and E85 as compared to this resource.

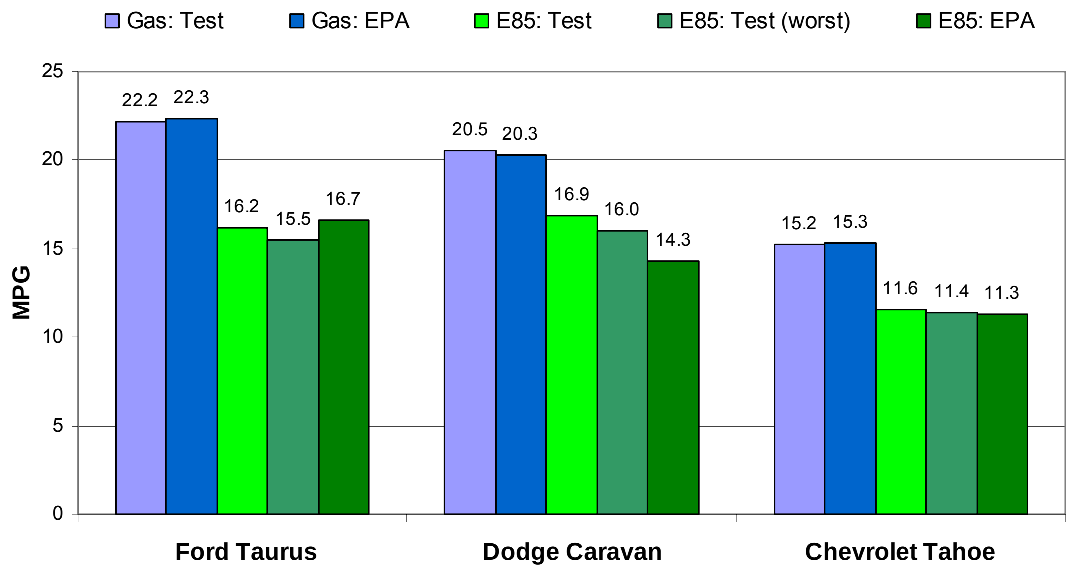


Figure 9: MPG calculations from testing results and EPA estimates

In comparison, for percentage of fuel economy drop the EPA estimated that the Ford Taurus decreased 29% (test: 27-30%), the Dodge Caravan decreased 30% (test: 18-22%), and the Chevrolet Tahoe decreased 26% (test: 24-25%). The largest variation occurred in the Dodge Caravan, which was found to have the lowest fuel economy drop in the testing, but the highest according to the EPA estimates. However, overall the EPA estimates are very similar to the test results. Therefore, EPA estimates were used in determining the overall percentage fuel economy drop for all Wake County flex-fueled vehicles since tests could not be performed on every model.

The year 2003 was chosen as a median year to use EPA fuel economy estimates for all the flex-fueled vehicles listed for Wake County. Using a 45% highway and 55% city driving mix, average mpg estimates were calculated with multiplying factors equal to the percentage of vehicle population. It was determined that the Wake County overall average for flex-fueled vehicles running on gasoline was 19.1 while for E85 this average was 13.8, representing a decrease of 27.9% in fuel economy. This is slightly higher than the 24.3% found in the testing, but still very close. Using EPA estimates for the flex-fueled vehicle models available in 2005, E85 decreased fuel economy by 25.6% showing improvements in FFV engine design, but the 2003 estimates are used in later calculations to account for older vehicles that may have greater fuel economy loss.

Since no E85 station was established to monitor the fuel usage or mix of flex-fueled vehicles that utilized the alternative fuel, assumptions will be made based on the project goals and overall vehicle mix for Wake County. We will assume that the E85 station will be used by $1/10^{th}$ of the vehicle owners in Wake County, 885, which is within the 800-1,000 user goal of the project. Knowing that it may not always be convenient to fill at this particular station, we will assume that only 10,000 miles of the commonly used yearly mileage of 15,000 will be run on E85. With these assumptions at a 13.8 mpg vehicle average for Wake County, 480,000 gallons of E85 would be used in a year at a single station. This usage would save 278,000 gallons of fossil fuels per year, calculating the gasoline needed for that same travel minus the gasoline needed in the E85 mixture. The table of flex-fueled vehicle mpg and usage/savings calculations can all be found in Appendix F.

This represents the fuel usage and savings at a single pump, and does not account for the production or transportation of each fuel. Unfortunately both of these processes require energy that is primarily provided by fossil fuels; oil for transportation and coal for electricity in production. Including a wells to wheel analysis for both gasoline and ethanol would require an extensive study to account for the all factors including the distance and means by which the resource is transported to the production facility, energy used in fertilizers and farm equipment to grow the feedstock, energy used to produce a useable fuel from the raw material, energy to transport that fuel to the filling station, and even additional costs associated with protection of the fuel supply which is often overlooked.

Summary

E85 is a viable alternative fuel that performs well in flex-fueled vehicles and will reduce our dependence on fossil fuels. There currently is a significant population of these vehicles in Wake County, but no E85 fueling stations. Ideally an E85 filling site would be located to accommodate fleet vehicles from one or more of the major fleets that have been identified, near Raleigh to maximize convenience for the largest number of private FFV owners, and easily accessible from a major highway to attract more commuter traffic. A location utilizing these three elements would most likely use over 100,000 gallons per year and probably sell considerably more if advertised effectively. However, in any advertising information the decline in fuel economy must be properly addressed so that consumers are not misled about the facts. As the testing and EPA estimates showed, there is a significant decrease in fuel economy when using E85 which must be justified with the other benefits of ethanol. These include the fact that every 100,000 gallons of E85 used will save 58,000 gallons of gasoline at the pumps, thus reducing the dependence on fossil fuels.

E85 ENVIRONMENTAL BENEFITS STUDY

E85 fuel contains 85% ethanol, which is an alcohol containing two carbon, six hydrogen, and one oxygen atom with the chemical formula of CH_3CH_2OH. Gasoline contains seven to eleven carbon atoms with two more than double that of hydrogen atoms (ie. the octane hydrocarbon gasoline chain has 8 carbon atoms and 2+(2*8) or 18 hydrogen atoms). Thus, the major difference between the two is the presence of oxygen in the ethanol. In the ideal combustion process the fuel combines with oxygen to produce carbon dioxide (CO_2) and water (H_2O). Unfortunately, pure oxygen is not easily or cheaply available, so we use air which contains 78% nitrogen, 20% oxygen, and other trace chemicals. Therefore, typically combustion also produces nitric oxides (caused by combining nitrogen and oxygen in high temperatures), carbon monoxide (caused by not enough oxygen to make carbon dioxide), and hydrocarbons (caused by extra fuel that was not combusted). Increasing the oxygen (as with the extra atom in ethanol) should help to reduce both carbon monoxide and hydrocarbons.

Emission benefits from using ethanol as a fuel has not been cut and dry. Theoretical models and computer simulations have been used by many to show a large reduction in greenhouse gas emissions. Others have run tests and found reductions in one emission, but increases in other chemicals released that are said to increase greenhouse gas emissions. In this study, actual emission readings were taken during an on-road test to evaluate the benefits accredited to E85 usage. The following sections will explain the testing procedure, equipment used, and results obtained through this experimentation.

Procedure

An on-road emissions test was used to best simulate real-world emissions from a flex-fueled vehicle. This was designed to coordinate with the fuel economy testing described in the E85 usage and fossil fuel savings study. The same three vehicles; Ford Taurus, Dodge Caravan, and Chevrolet Tahoe, were used on the identical route that combined 33% 60-mph highway driving with the remaining city driving at 35 or 45 mph with stops. Two quick accelerations were done on each trip while all other accelerations were normal. As described previously, each vehicle was tested on a full tank of E85 and a full tank of gasoline. The testing took place from April through June, with an average period of two weeks to complete the tests before returning the vehicles.

To ensure that the fuel was properly mixed and the engine was running entirely on the desired fuel, ten complete route trips were made. This totaled 120 miles or about a quarter to a third of the fuel tank capacity. All of the beginning, testing, and concluding runs were completed with closed windows, fixed interior air cooling settings, and at low traffic times to eliminate additional slow driving periods or stops. After conditioning the engine to the fuel, the vehicle was equipped for recording emissions tests.

An Interro Systems 5 Gas Emissions Analyzer was used to measure the emissions during the on-road testing. This system was easily integrated into the testing vehicle and interfaced with a laptop computer to record all data that could later be analyzed using the Interro or other computer software. The system was powered through the vehicle's 12-V DC dashboard outlet, with inputs from a sample probe in the exhaust pipe and rpm lead connected to the engine's spark plug wires. A water exhaust tube exited the 5 Gas Analyzer which was run outside the vehicle, while a serial cable allowed the laptop to interact and monitor the results obtained by the system. Figure 10 shows how the system was installed onto the vehicles with the computer display accessible for the driver to monitor during the tests. Appendix G has the data information for the Interro 4/5 Gas Emissions Analyzer.

The gas analyzer was calibrated at the beginning of the tests and after the Caravan runs to ensure its accurate performance. Leak tests were performed occasionally and the tailpipe probe was cleaned after each vehicle completed the tests. A new sample filter was used after testing the Taurus, but it dried out and cracked during a weekend break from testing the Caravan. Alternative filters were tried before using the older original filter. During this time, test runs recorded significantly higher oxygen levels and lower carbon dioxide levels. It was finally determined that the filter housing was not properly sealed, thus producing a leak in the system. Once tightened and leak tested, recordings returned to expected levels. However, two E85 tests were then invalid and could not be replaced because the vehicle was already using gasoline. The three bad gasoline tests could be redone since enough gasoline remained in the vehicle after the original tests were completed.

Figure 10: Emission testing set-up with 5 gas PDA analyzer and laptop interface

Ten emission test trips were conducted with each vehicle using both E85 and gasoline. Testing was run on weekdays from 9:30am to 11:00am and from 1:30pm to 4:00pm, or on weekends to avoid traffic congestion. Five-minute warm-up time was given for both the engine and the analyzer along with an initial test as the vehicle was driven from the NC

Solar Center's Alternative Fuel Vehicle garage to a gravel parking lot next to the road. This was done to flush any emissions from previous runs or the idle time.

At the start and throughout the trip times were recorded for each point that the vehicle slowed down or stopped. This was used in the post analysis to identify specific patterns of driving that could be compared for the two different fuels. A sample time sheet can be found in Appendix H for a Tahoe test on E85 fuel. This shows that the PDA gas analyzer had to be reset at two different points during the testing run. This was because the analyzer could only record 600 seconds (10 minutes) of data for each gas test. Therefore stops were set in the route to reset the gas analyzer and except for a few rare cases the analyzer never reached its 600 second limit and all data was recorded. Occasionally, when traffic prevented a smooth run and it appeared that the analyzer might time out, the system was reset at a stop light to prevent it from happening. Only once did the test last over 30 minutes, at which time the analyzer requests a zeroing to calibrate it and flush out the exhaust inside the system. At the conclusion of each run, the 5 gas analyzer was allowed to run while the emissions data was exported from the gas analyzer software into a more usable format.

Running the pump for 30 minutes after each test helped to regulate the system and prevent emissions from building up inside the analyzer. The vehicle could also cool down during this time to prepare for the next test run. Ideally the engine would be completely at ambient temperature before starting another test run, but this was not feasible with the limited testing time. At most five tests runs were performed in a single day with at least a 30 minute break from the end of one test to the beginning of the next. There was also a two-hour break in the middle of the day between the first two runs and the last three runs of the day.

Results

The Interro 5 Gas Emissions Analyzer measured RPM, Air to Fuel Ratio, percentages of carbon dioxide, carbon monoxide, and oxygen, as well as parts per million of nitric oxides and hydrocarbons. Ten test runs were conducted for each vehicle running on two fuels; E85 and gasoline. For each test run, three gas tests were combined to create a profile for each of the eight measurements taken by the gas analyzer and an average emission rate was determined. These were averaged over all ten test runs to compare the emissions performance of the two different fuels.

Averages for the 2004 Ford Taurus are shown on Table 2 for all five emissions gases and the air to fuel ratio. In addition, the average rpm calculated shows that the runs on each fuel were similar. Of the five gases, only carbon monoxide showed a significant decrease when using E85 instead of gasoline. All of the other emission gases were similar and varied enough in the tests that the standard deviation for all runs is greater than the difference between E85 and gasoline.

Table 2: Ford Taurus gas emissions averages

Ford Taurus		Ten-run Average		Standard Deviation	
RPM	Gas	2760		+/-	89
	E85	2740		+/-	117
AFR	Gas	13.6		+/-	1.90
	E85	14.3		+/-	1.26
CO2	Gas	15.0	%	+/-	0.11
	E85	15.1	%	+/-	0.04
CO	Gas	0.0437	%	+/-	0.0087
	E85	0.0016	%	+/-	0.0027
O2	Gas	0.0873	%	+/-	0.0160
	E85	0.1230	%	+/-	0.0816
Nox	Gas	22.6	ppm	+/-	5.50
	E85	19.9	ppm	+/-	4.04
HC	Gas	26.7	ppm	+/-	23.6
	E85	22.3	ppm	+/-	21.9

Similarly, Table 3 shows the five emission gas averages for the 2005 Dodge Caravan, the average air to fuel ratio and the rpm average. For this vehicle, both carbon monoxide and carbon dioxide showed reductions with E85. However, the nitric oxides increased while the oxygen remained the same and the hydrocarbons were too varied in the different runs to report any difference with confidence.

Table 3: Dodge Caravan gas emissions averages

Dodge Caravan		Ten-run Average		Standard Deviation	
RPM	Gas	2800		+/-	84
	E85	2770		+/-	79
AFR	Gas	14.4		+/-	1.18
	E85	12.5		+/-	4.19
CO2	Gas	16.0	%	+/-	0.0867
	E85	14.9	%	+/-	0.0651
CO	Gas	0.0269	%	+/-	0.0032
	E85	0.0108	%	+/-	0.0069
O2	Gas	0.1405	%	+/-	0.0176
	E85	0.1471	%	+/-	0.0105
Nox	Gas	3.98	ppm	+/-	0.60
	E85	5.53	ppm	+/-	1.42
HC	Gas	39.6	ppm	+/-	25.6
	E85	29.3	ppm	+/-	28.2

The 2004 Chevrolet Tahoe emission averages are shown in Table 4. Again, the rpm averages show that the E85 and gasoline runs were very similar over all ten trips. Also, the averages of the five emission gases were very similar for both fuels and no distinction could be made for carbon dioxide, carbon monoxide, oxygen, or hydrocarbons. However, there was a measurable difference in the nitric oxides which showed a decrease when using E85, contrary to the results from the Caravan testing.

Table 4: Chevy Tahoe gas emissions averages

Chevy Tahoe		Ten-run Average		Standard Deviation	
RPM	Gas	1220		+/-	29
	E85	1200		+/-	28
AFR	Gas	6.48		+/-	5.30
	E85	5.52		+/-	4.41
CO2	Gas	16.03	%	+/-	0.13
	E85	16.01	%	+/-	0.10
CO	Gas	0.0002	%	+/-	0.0007
	E85	0.0004	%	+/-	0.0012
O2	Gas	0.1265	%	+/-	0.0400
	E85	0.1374	%	+/-	0.0343
Nox	Gas	7.58	ppm	+/-	1.34
	E85	5.04	ppm	+/-	0.60
HC	Gas	2.22	ppm	+/-	2.91
	E85	1.43	ppm	+/-	1.57

Complete sets of averages for each individual run with charts for the Taurus, Caravan, and Tahoe can be found in Appendices I, J, and K respectively. Averages, however, don't tell the whole story. The measurements by the analyzer are based on a percentage or fraction of the total emission flow, which is not measured by the 5 gas analyzer. An attempt was made to record the air flow through the vehicle's on-board-diagnostic (OBD) system, but the Ford Taurus was not compatible with the DriveRight Carchip system (specifications found in Appendix L) that was used and the other two vehicles were compatible, but not programmed to provide the airflow information. Therefore, the fuel economy results were used to provide a comparison. This was done because if the E85 fuel is used at a faster rate (less mpg) than gasoline, then the airflow will be greater to maintain the similar air to fuel ratios seen with the two.

The Interro Analyzer software can be used to calculate the mass emissions estimate for the recorded gas tests. For the road tests, three consecutive gas test estimates were factored by length of that particular test to determine the mass emissions for the entire trip. The exact calculation used is not given, however the manual states that the formula relies on a series of assumptions, revolving around the amount of fuel being burned, to estimate exhaust volumes and subsequent mass emissions. Thus, these are greatly influenced by the user inputted miles per gallon value. For these three vehicles, the results from the E85 usage and fossil fuel savings study were used;

Ford Taurus:	Gas – 22.2 mpg, E85 – 16.2 mpg
Dodge Caravan:	Gas – 20.5 mpg, E85 – 16.5 mpg
Chevrolet Tahoe:	Gas – 15.5 mpg, E85 – 11.8 mpg

Comparing some average and mass emission results, it can be shown how the fuel economy difference affects the exhaust flow rate and the emissions. For example, the Caravan showed a 7% decrease in carbon dioxide for the averages, but a 24% increase for the mass emissions. A significant 34% decrease in nitric oxides was found for the Tahoe with the averages, but the mass emissions calculated this to be only a 10% decrease.

The mass emissions values for all test runs are tabulated in Appendices I, J, and K for the Taurus, Caravan, and Tahoe respectively with the individual trip estimates and overall vehicle estimates graphed as well. Table 5 summarizes the three tested vehicle's mass emission estimates for carbon monoxide, carbon dioxide, nitric oxides, and hydrocarbons.

Table 5: Mass emissions estimates for the tested vehicles on gasoline and E85

		Gasoline			Ethanol; E85			% Change
CO	**Taurus**	0.7237	+/-	0.1519	0.0417	+/-	0.0481	-94.2%
	Caravan	0.4601	+/-	0.0593	0.2472	+/-	0.1012	-46.3%
	Tahoe	0.0376	+/-	0.0159	0.0319	+/-	0.0212	-15.2%
CO2	**Taurus**	395.2	+/-	0.2418	543.1	+/-	0.0681	37.4%
	Caravan	428.4	+/-	0.0849	532.8	+/-	0.1048	24.4%
	Tahoe	567.7	+/-	0.0283	745.7	+/-	0.0325	31.4%
Nox	**Taurus**	0.0625	+/-	0.0151	0.0751	+/-	0.0162	20.2%
	Caravan	0.0114	+/-	0.0026	0.0214	+/-	0.0046	87.7%
	Tahoe	0.0297	+/-	0.0041	0.0267	+/-	0.0041	-10.1%
HC	**Taurus**	0.1371	+/-	0.1213	0.1565	+/-	0.1466	14.2%
	Caravan	0.2088	+/-	0.1350	0.2050	+/-	0.1984	-1.8%
	Tahoe	0.0156	+/-	0.0207	0.0130	+/-	0.0149	-16.7%

Highlighted rows indicate significant emission changes from the vehicles using the different fuels. The other values show slight changes in the emissions, but the variance in the testing trips shown by the standard deviation was too great to draw a conclusion from the results. All results are graphed on Figure 11. As mentioned before, all percentage differences 20% or less indicate a trend, but can not be numerically justified with the value's standard deviation.

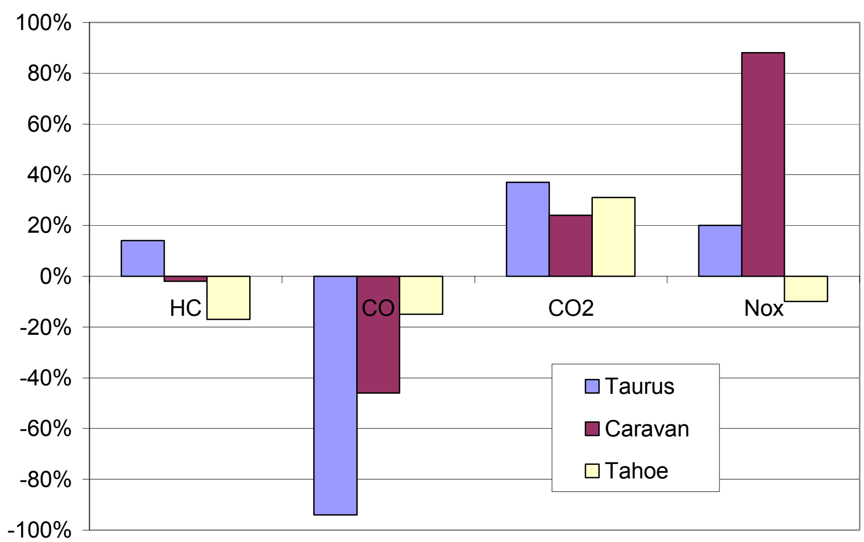


Figure 11: Mass emission percentage differences from using E85 instead of gasoline

As shown, the test results for the two fuels vary greatly with the three vehicles. Both hydrocarbon and nitric oxide results show both increases and decreases depending on the vehicle. Most of these differences for these two emissions are 20% or less indicating little validity in their exactness. However, there was a significant increase in nitric oxides for the Caravan with E85 which draws concern but would need to be retested to verify since the other flex-fueled vehicles did not show results close to that. In the case of carbon dioxide, the results were similar for each vehicle showing an overall 31% increase. Although the results for carbon monoxide varied greatly with the vehicles, each showed a decrease with an overall average of 52% less by using E85.

The majority of the emissions during the test route occurred at accelerations as the vehicle increased speed after coming to rest at a stoplight or stop sign. Emission data for these specific times of the tests could be obtained from the five-gas analyzer by identifying the period of acceleration or deceleration from the testing time sheets and RPM output. All significant occurrences where the test vehicle had three or more similar stops for both E85 and gasoline were analyzed by averaging and comparing the emissions data for both fuels. Data for the E85 emissions are adjusted to reflect the loss in fuel economy between the two fuels. Four of these individual emission events are discussed to show the actual emission outputs as the vehicles progress through their acceleration or deceleration. An example of the plotted averages for an individual emissions event is shown in Figure 12. A complete set of emission events for each of the vehicles can be found in Appendix M and may be useful to refer to during the following discussion.

At the beginning of the test run when the vehicle stops at the intersection of Varsity and Western, a hard acceleration was performed which either led to a stop at the intersection of Western and Gorman or a continuation at 45 mph. The Taurus had an evenly split occurrence of both of these situations, while the Tahoe was analyzed for stopping at the Western/Gorman intersection and the Caravan was analyzed for continuing at 45 mph. RPM plots show similar driving patterns for the vehicle on E85 and gasoline. The carbon monoxide emissions showed significant decreases for the Taurus and Caravan, however, the Tahoe showed an increase. The hydrocarbon emission results were not conclusive for this event, but every vehicle showed a slight increase in nitric oxide emissions.

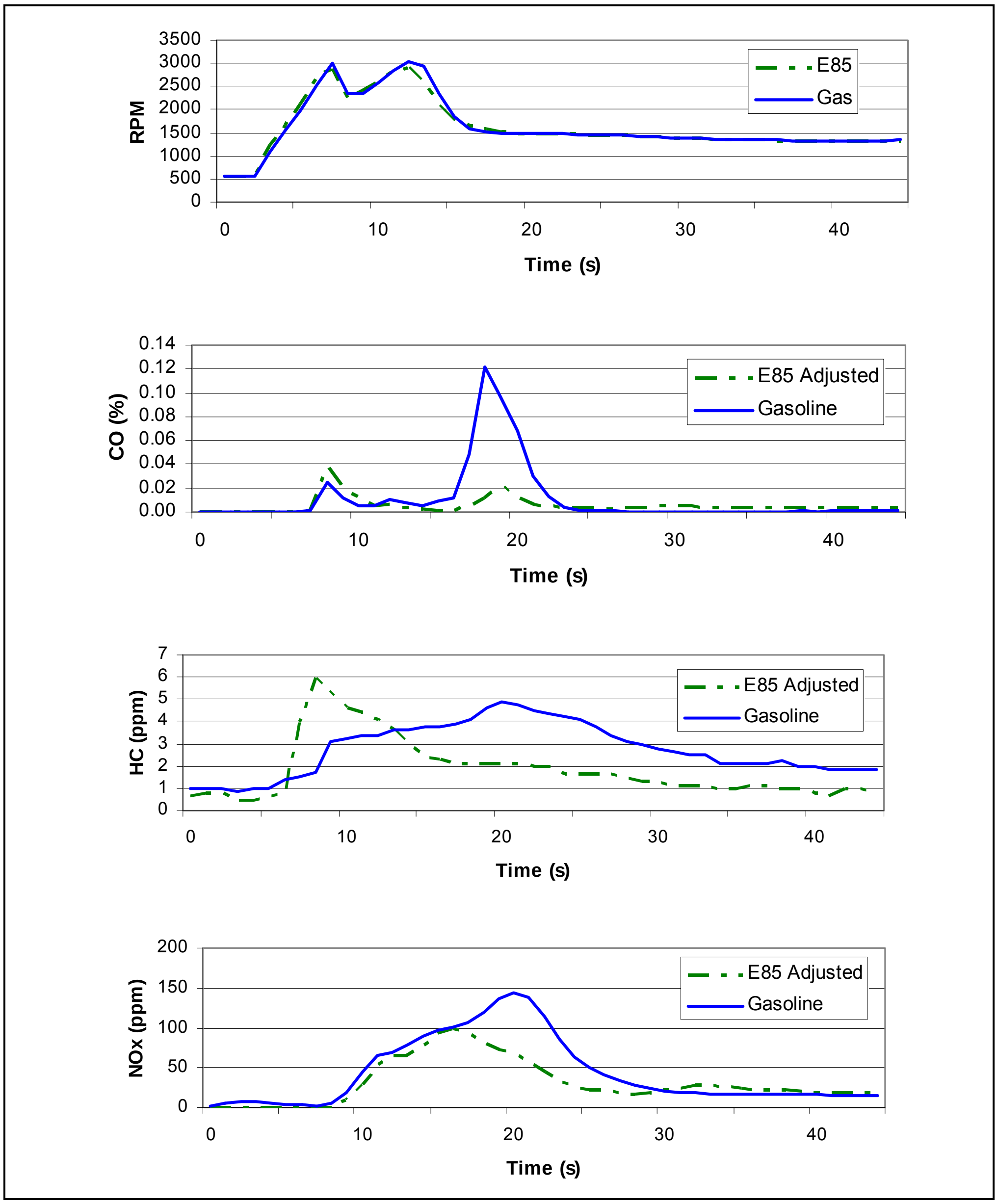


Figure 12: Individual emissions event example

The second emission event looked at the deceleration from Interstate 440 at 60 mph to exit for Glenwood Avenue, where the vehicle had to accelerate on a slight incline to reach 45 mph before stopping at the Glenwood/Pasquotank intersection. Each vehicle had sufficient occurrences for this event and showed similar RPM averages for each fuel. On the deceleration, each vehicle showed increases in carbon monoxide for gasoline while on E85 this did not occur. Upon accelerating after the off-ramp on Glenwood, the Taurus had no

CO emissions for either fuel, the Caravan had increases for both, and the Tahoe had slightly higher CO emissions with E85. Hydrocarbon and nitric oxide emissions were similar for both fuels on all three vehicles for this event, except that the Taurus did show a slight increase in HC with gasoline on the deceleration and the Caravan had slightly more nitric oxide emissions with E85.

The next emission event is an acceleration to 35 mph on Glenwood Avenue after stopping at a light where Oberlin Drive intersects it. This acceleration occurs on a slight incline causing the engines to work harder and emit more pollutants. Each vehicle shows a decrease in carbon monoxide emissions by using E85. Hydrocarbon emissions are similar for the Taurus on both fuels, while both the Caravan and Tahoe show slightly higher increases on HC with gasoline. Results for nitric oxide emissions are mixed with the Taurus and Tahoe showing less emitted with E85, but the Caravan has more.

The hard acceleration on Western Boulevard after stopping at the end of Ashe Avenue is the final emission event analyzed. Similar RPM values indicate a similar driving pattern for the vehicles on the two different fuels. Carbon monoxide emission averages show significantly higher values for gasoline with the Taurus and Tahoe. The Caravan shows similar CO values on these two fuels for this particular event. Hydrocarbon emissions are very similar for the Taurus and Caravan on either fuel as they show a slow increase over the time of this event, while the Tahoe shows the emission peaking at different times for E85 and gasoline but neither is significantly greater than the other. Both the Taurus and Caravan also show greater increases of nitric oxides with E85 during this hard acceleration. The Tahoe's nitric oxide emissions, however, are slightly lower with E85.

The last emission event is an acceleration to 35 mph on Glenwood Avenue after stopping at a light where Oberlin Drive intersects it. This acceleration occurs on a slight incline causing the engines to work harder and emit more pollutants. Each vehicle shows a decrease in carbon monoxide emissions by using E85. Hydrocarbon emissions are similar for the Taurus on both fuels, while both the Caravan and Tahoe show slightly higher increases on HC with gasoline. Results for nitric oxide emissions are mixed with the Taurus and Tahoe showing less emitted with E85, but the Caravan has more.

While many of the plotted averages from the individual emission events show some variance in the patterns, a few overall results can be seen. Ten of the thirteen carbon monoxide plots showed significant decreases when using E85 as a fuel which is consistent with the PDA results. Hydrocarbon emissions were fairly similar for all emission events showing little difference between the two fuels. There were also never any large peaks in HC emissions during the events like seen in the other two pollutants. For the nitric oxide, the majority (8) of the plotted averages showed an increase when using E85. Unlike the PDA results though, it was not only the Caravan that showed these increases. However, there were three cases in different events where the nitric oxides were considerably less with using E85.

Similar variance in emission levels can be seen in the EPA's Annual Certification Test Results Report, where emission levels in flex-fueled vehicles for E85 and gasoline tend to vary significantly from vehicle to vehicle and even year to year. The EPA annually tests certification levels of vehicles for emission standards and must perform the tests for all fuels that a vehicle can operate on. Therefore, flex-fueled vehicles are tested on both gasoline and E85, while others are even tested with E10. Analyzing the data from these tests shows that conclusive emission trends from E85 fuel testing are nearly impossible. Figure 13 shows the carbon monoxide results for eight 2005 flex-fueled vehicles and the overall average. Although on average there was a decrease in carbon monoxide emissions, individually, half of the vehicles showed an increase. The overall average was most likely affected primarily by the Dodge Ram 1500 pickup results that showed an 83% decrease. However, the 2004 Dodge Ram 1500 pickup results showed a 20% increase in carbon monoxide emissions. Similar variant results can be seen with the complete flex-fueled carbon monoxide results from 2002-2005 in Appendix N where overall averages for E85 were identical in 2002, slightly lower in 2003, and slightly higher in 2004.

Similar inconclusive trends are seen in the EPA's nitric oxide results as well. The 2005 results are shown in Figure 14. Three flex-fueled vehicles showed no difference in the emission with E85, while two showed a decrease and three an increase. The overall average was a slight increase, which was similar to the results from previous years as shown in Appendix O. Again we can see highly varied results, as with the Mercury Mountaineer that had lower NOx emissions with E85 in 2002, identical in 2003, lower again in 2004, then an increase in 2005. Since the EPA is only interested in the vehicles meeting certain certification levels, these test results are most likely less precise and more limited than specific research results. However, they do indicate a large variance in the different available flex-fueled vehicles, but overall very little emission increases or decreases by using E85.

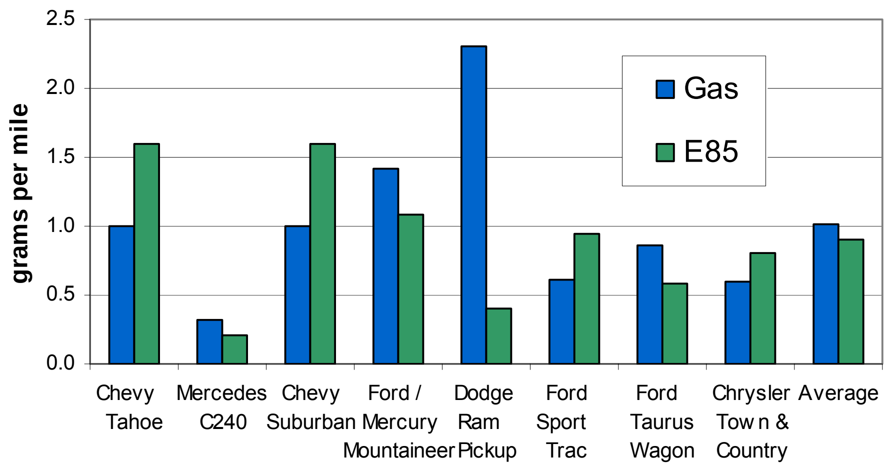


Figure 13: Carbon monoxide emission results from EPA Certifications [17]

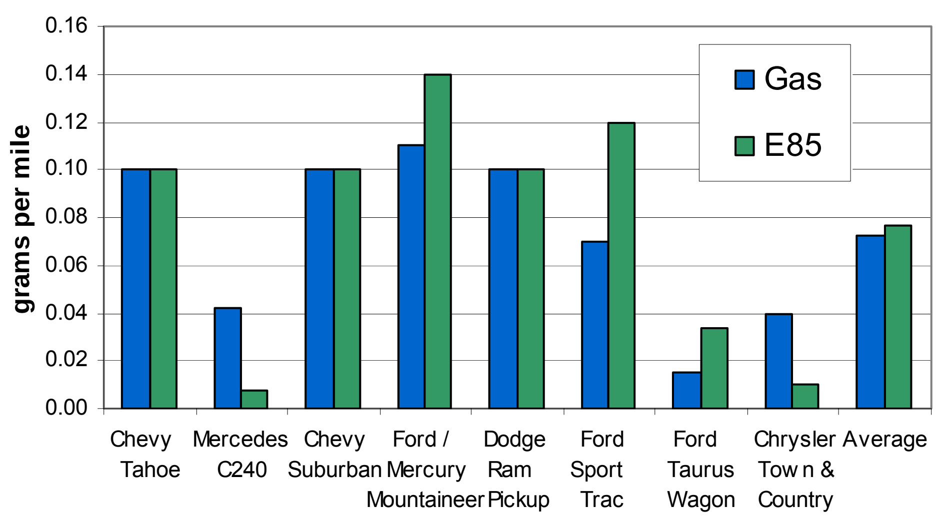


Figure 14: Nitric oxide emission results from EPA Certifications [17]

Summary

Even though only three flex-fueled vehicles were tested with a single tank of fuel of either gasoline or E85, multiple test runs were conducted that showed similar driving patterns and conditions for a valid comparison. When factoring in the fuel economy differences general patterns of emissions can be seen from the use of the two fuels. The varied results for nitric oxides and hydrocarbons showed that there were likely very little differences in the amount of these two emissions for E85 as compared to gasoline.

The results did show an increase in carbon dioxide emissions however, which can be attributed to the lower energy content of ethanol as compared to gasoline. Molecularly the bonds in gasoline are stronger with more energy, so to produce the same energy out of the combustion process that splits these bonds, more carbon-hydrogen bonds in the ethanol need to be broken which produces more carbon dioxide. What is not factored in is the production process for each of these fuels which would dramatically change this result. Ethanol produced from plants (corn) uses carbon dioxide to grow, thus taking this emission out of the air. Using E85 contributes to the carbon cycle, with plants taking it out of the air, plants storing it in sugars that are used to make ethanol, and vehicles releasing the carbon back into the air. The production of gasoline, on the other hand, only adds to the amount of carbon dioxide in the air. In that process, carbon that was once buried in the ground is now brought to the surface and added to the carbon cycle, an increase that has contributed to global warming. So although vehicle carbon dioxide emissions for flex-fueled vehicles on E85 are higher than gasoline, overall, the use of ethanol as a fuel will not add additional carbon to the environment like gasoline does.

These emission results did confirm that E85 burns more completely than gasoline through its reduction of carbon monoxide emissions. Even with the increase in fuel consumption, because ethanol contains an oxygen atom the combustion process produces less carbon monoxide. This is a regulated emission that needs to be lowered in many areas that are not meeting the federal standards, including North Carolina. Although the percentages varied by vehicle, each one showed improvements using E85, with the Taurus showing the highest carbon monoxide reduction of 94%. On average for these three vehicles, running on gasoline produced 0.41 grams per mile of carbon monoxide while on E85 these vehicles only produced 0.11 grams per mile. Using the proposed usage numbers of 6,640,000 miles driven on flex-fueled vehicles with E85, 4,400 pounds of carbon monoxide will be saved from one E85 station.

This study focused on the emissions of oxygen, carbon dioxide, carbon monoxide, nitric oxides and hydrocarbons; however there are other toxic air pollutants that are emitted from vehicles. These are from the added octane enhancing toxic aromatic components. Ethanol itself is an octane enhancer, which eliminates the need of these or others, including MTBE, a man-made petroleum derived chemical used to oxygenate gasoline. An ethanol and gasoline mixture increases vapor pressure so it more easily evaporates, which increases VOC emissions. It has also been found that E85 tailpipe emissions are higher in acetaldehyde and peroxyacetyl nitrate, but lower in benzene, xylene, PM10 and other toxic or hazardous pollutants. Overall, it has been determined that ethanol use will cause a 1% increase in the toxic emissions on a mass basis, but a 2% decrease in the potency (ability to cause cancer) of these toxic emissions compared to MTBE. If MTBE is treated as a potential carcinogen, as many believe it is, the toxic emission savings of ethanol is even greater [18].

AWARENESS LEVEL SURVEY

To assess the awareness of the use of ethanol as a fuel, a random survey of the general public in Wake County was conducted from February to June, 2005. Owners of flex-fueled vehicles were specifically targeted to evaluate their knowledge of their vehicle's fuel capability and their willingness to use E85. In addition to answering a few questions, the owners gained information about E85 specific to Wake County and North Carolina. It was an excellent opportunity to reach out to potential alternative fuel users, answering any questions they might have as well as assessing the obstacles (as expressed by the owners) that E85 or any alternative fuel must overcome to be marketable. The following sections describe the procedure used to develop and carry out the awareness survey, the development of the questions, detailed statistical results, and an overall summary drawn from this assessment.

Procedure

A phone survey was chosen over mailing or internet methods to obtain the highest response rate and ensure that the participants were randomly selected from all Wake County flex-fueled vehicle owners. The Wake county flex-fueled vehicle list described earlier in this report was used to identify the 6,423 private owners who would be the subjects of this survey. Each entry was assigned a randomly generated number in Microsoft Excel [=rand()*6423], then sorted by that random number. The first 1,000 entries were chosen to be the sampling pool, after checking for any duplicated names or addresses.

The survey questions were developed based on three primary questions:

Do owners know if their vehicle is flex-fueled?

What are their concerns about the current fuel situation?

Would they consider using an alternative fuel?

An initial survey with an introduction, question list, and conclusion was created to address the primary three questions while not overwhelming the participants with too many questions. A goal of 5 minutes and 10 questions was suggested by an experienced survey developer, who also made several suggestions for the second revision. As shown in the survey revisions found in Appendix P, the second revision developed the questions into a survey format that could tally the corresponding answers and values. Additional modifications included explaining how their name was chosen, eliminating personal information, and listing possible answers to the questions. This was later revised a third and final time after meeting with the NCSU Statistical Consulting Center, where they suggested adding a 'none' answer to question 7 and rearranging the questions to flow better. In addition, after making a few initial calls, it was determined that the yearly mileage question should be eliminated because many found it hard to answer and it had little significance on the overall survey. Also, the introduction was arranged to ask them immediately if they wished to participate so it would not waste additional time if they were not interested or busy at that time. Thus, the final revision found in Appendix Q was used to conduct the phone call awareness survey from March to June during the evening hours of 7pm - 9pm, unless indicated by the participants that a different time would be better.

The NCSU Institutional Review Board for the Use of Human Subject in Research must approve any survey conducted through the university. Because the survey did not contain any potential incriminating questions and the participants' names would not be used in any published documents, it was exempt from an extensive review process. The application and exemption approval letter can be found in Appendix R.

A sampling size of 400 participants was established as a goal in discussion with the NCSU Statistical Consulting Center based on an evenly split two-answer question for a 95% confidence interval of +/- 0.05. The consulting report found in Appendix S also indicates that an evenly split four-answer question would create a 90% confidence interval of +/- 0.05 for the same sampling size.

Using the Wake County flex-fueled vehicle owners' list, phone numbers for the 1,000 selected subjects were researched on the internet. Based on the participant's name and address, 742 phone numbers were found. Each of these randomly selected owners was then called at least twice on different evenings at 7pm to 9pm from March to June. Those that provided me with an alternative time to call back were often tried many more times. About 15-20 responses were gathered on each evening that the survey was conducted. After progressing twice through the list, it was determined that further responses would be minimal, and time constrains limited the ability to select an additional group of owners.

Of the 742 found phone numbers of flex-fueled owners, 207 were never reached due to being screened by an answering machine or calling when they weren't home. Eighty-seven numbers had been disconnected, wrong, a modem, or a home where the vehicle owner had moved. For the remaining 448 that answered, 308 (69%) answered the survey, 87 (19%) refused to participate, and 53 (12%) gave a different time to call back but were never able to be reached again.

Results

Once the survey began, many participants were very engaged in the topic and answered the questions with further explanations of their opinions. A complete list of the survey responses can be found in Appendix T along with any additional comments or reasoning for answering differently than the suggested answers. These answers are also tallied and summarized in Appendix U where you will also find the margin of error for a 90% confidence interval based on the following equation;

$$d = (x/2) * [Z_{\alpha/2} * \sqrt{p(1-p)}] / \sqrt{n}$$

where: $Z_{\alpha/2}$ = 1.645 (90% Confidence Interval)

p = proportion of affirmative responses

x = number of possible answers

n = sample size

d = margin of error

With the generally skewed proportions of responses in the survey, it was found that 300 responses provided a margin of error within +/- 5% (90% CI) for all questions that had only two possible answers. This is a higher confidence level than originally desired, but provides a reasonable margin of error for only reaching ¾ of the sampling size goal. Most questions with three or four possible answers had margins of error within +/- 10% (90% CI). This margin of error can be assumed for all of the following percentages given in this section unless otherwise indicated. The results for each question, written in italics, will now be addressed individually with explanations and interpretations as necessary.

Q1: Do you still own a YEAR-MAKE-MODEL? The purpose of this question was to confirm that the participant did still own the flex-fueled vehicle in question. Originally the intention was to politely end the survey if they did not still own the vehicle, but due to the difficulty in finding willing participants, the survey skipped to question 5 for these participants so that they could still contribute their opinion for being willing to answer the survey. Of the 308 responses, 288 (94%) still owned a flex-fueled vehicle including a few that had traded an older one in for a newer model. The majority of those not still owning their vehicle had older minivans, although some claimed to never have owned the vehicle in question which may have come from a faulty vehicle or phone number listing.

Q2: What fuel grade do you typically use? The purpose of this question was to compare prices between what they normally pay to what they would have to pay for E85. Most owners use regular (or "the cheapest one" as was most commonly answered), followed by mid-grade, then premium. The percentages were 87%, 9%, and 4% respectively. This likely reflects the general public, although no flex-fueled vehicles are luxury models that recommend premium fuels so that could affect the comparison. This result will be visited later when discussing question 8.

Q3: Can your vehicle run on any fuel other than gasoline? In other words, this asked if they knew they owned a flex-fueled vehicle while eliminating the term "flex-fueled" that might confuse them. Originally, this was a yes or no question, but later adjusted to reflect those that responded with 'I don't know". Surprisingly, only 13% actually knew that their vehicle could run on another fuel. With no E85 filling stations in the area the owners may not have been told about it from the manufacturer or sales representative. However, for as many times as these owners have opened their gas covers (where vehicles are required to provide fueling information) it is amazing that so many have not noticed. In addition, there was a significant percentage more that answered 'no' instead of 'I don't know' as shown in Figure 15.

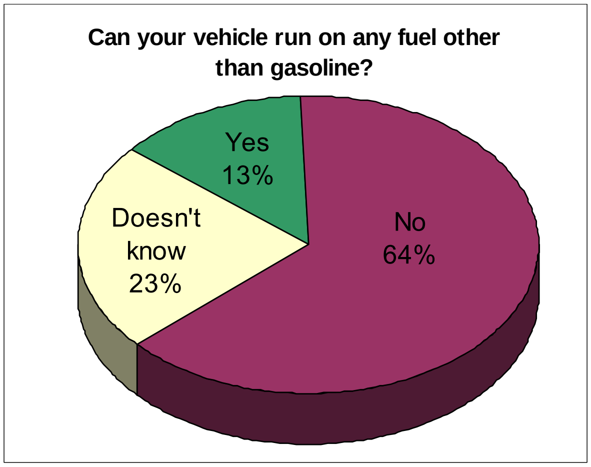


Figure 15: Pie charted results for survey question 3

Q4: For those that knew, how big of a factor was having an alternative fueled vehicle when deciding to purchasing it? Since only a few participants that knew their vehicle was a flex-fueled vehicle, there was a relatively small sample size for this question. This caused the margin of error to increase above the +/- 10%. However, the results were still considerably skewed which kept the error within +/- 20%. Following the results and reasoning for the previous question, it is not surprising to see 74% indicate that being alternatively fueled was not at all a factor when they were deciding to purchase the vehicle. Those that did consider it a factor when buying the vehicle, as shown on Figure 16, were obviously upset that they have yet to find the fuel available and were encouraged by the goals of this project.

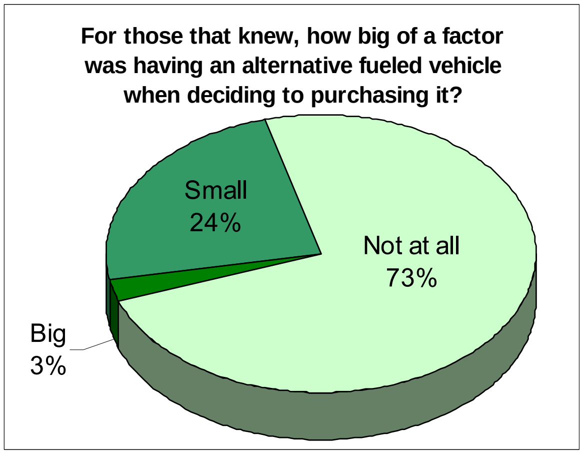


Figure 16: Pie charted results for survey question 4

Q5: How concerned are you about the state of fuel in the US? Survey responses fluctuate over time, and one must consider the timing of this survey with the events that took place during it. These include the extension of the military action in Iraq, national fuel price increase of 30 cents from January to June 2005, and increased media coverage on fuel issues due to these first two events. Therefore, it is easy to understand why Figure 17 shows 82% responding as being either very or moderately concerned about the state of fuel in the US. This is most likely an increase from 6 months to a year ago, but it is hard to predict if it will remain this high 6 months to a year from now. All indications are pointing towards energy/fuel being a hot issue for the next many years, with opportunities to really push forward with alternatives.

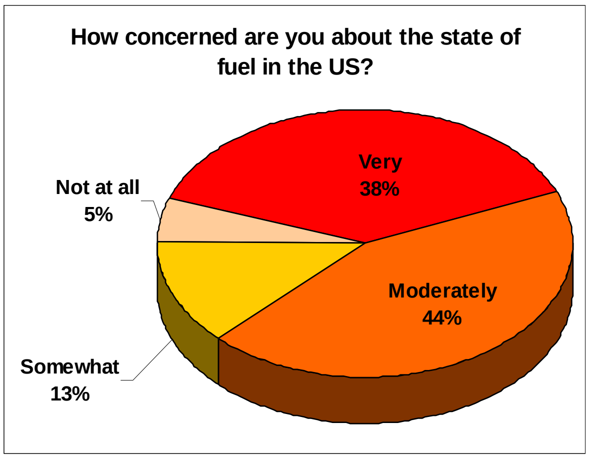


Figure 17: Pie charted results for survey question 5

Q6: What is your biggest concern related to fuel? After providing the choices, the most frequent response to this question was 'all of the above'. This was rejected so that they could answer with their biggest concern, yet even this resulted in multiple answers (the first was chosen) or a persistent 'all of them'. However, the two issues mentioned in the last question analysis that have caught most of the media attention over the last few months were reflected in the participants' answers. The highest scoring answer was rising cost (39%) with the dependence on foreign countries close behind (30%). Although, as shown in Figure 18, both limited supply and pollution were selected a number of times as well.

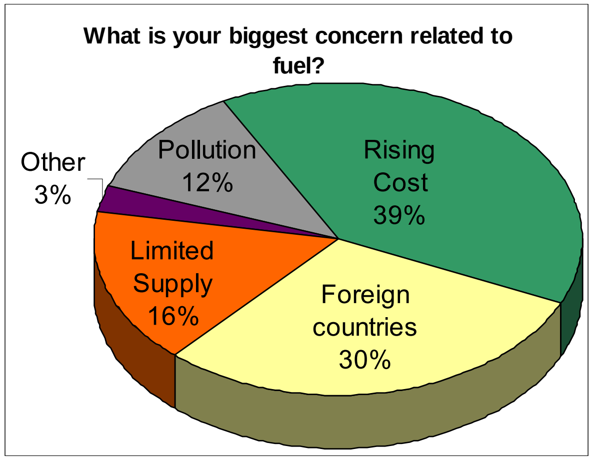


Figure 18: Pie charted results for survey question 6

Q7: If available, would you buy an alternative fuel that is made in the US from renewable resources and causes less pollution? A number of participants were ready to skip to the next question by asking "does it cost more?", which stems from the majority answering that the rising cost of fuel was their biggest concern. However, this showed they were listening to the questions and engaged in the topic so it was very encouraging. Overwhelmingly, 93% said yes to this question, many responding even before the question was finished. Of course, the question was written in view of E85 fulfilling the promises listed in the question, and the emissions reduction may not be necessarily that significant. But pollution was the lowest concern in question 6, which tends to indicate that even if the question eliminated the last 'and causes less pollution' a significant majority would still answer yes. Some of those not ready to answer this question showed reserve in just doing something because it sounds really good and wanted more information on the fuel before committing their vehicle to it.

Q8: How much more per gallon would you be willing to pay for that alternative fuel? This question really hit home, and almost every participant gave a groan as the question was read. Many had to take a little time to think about this one, as cents doesn't sound like a lot until you have to fill a twenty plus tank every week. Still, there were almost as many that answered '20 cents or more' as those that answered 'none'. In retrospect, the answers probably should have been 10, 25, or 50 cents to really separate those willing to spend extra to buy an alternative fuel. This would also better reflect the loss from fuel economy, because if the cost of E85 were the same as regular (the choice of gas for most participants), around $2.20 per gallon, a 25% drop in fuel economy would translate to a 55 cents more per gallon cost. The fairly even distribution of answers for this question can be seen on Figure 19.

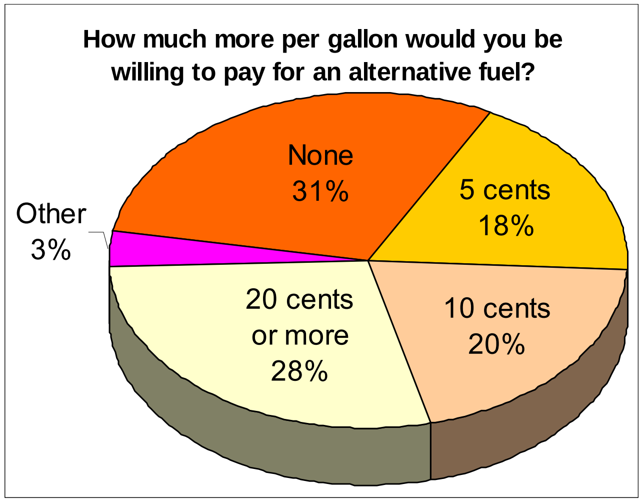


Figure 19: Pie charted results for survey question 8

Q9: If performance, cost, and style were similar to conventional gasoline vehicles, would you choose to buy a new vehicle that would run on an alternative fuel? For those that were apprehensive about telemarketers and phone surveys, they thought I had tricked them with the previous questions and had intentions to sell them a new vehicle. But after I assured them I was not a car salesman, 85% said that yes, they would probably consider an alternative fueled vehicle when they were ready to buy one. It had to be explained that current hybrid vehicles are not alternative fueled vehicles, although they are more efficient and do reduce our dependence on foreign oil. Again, like the last two questions, there were a good handful that were apprehensive about committing to an alternative, especially if it meant a large expense like a new vehicle. However, many raised valid concerns about fuel availability, reliability, and vehicle warrantees.

Most at this point still didn't realize that they owned an alternative fueled vehicle already, so this was a good conclusion to the survey where they could receive some good news. Then they would proceed to ask where they can get E85, and thus the goal of this project can be shared. Unfortunately, towards the end of the project when it was known that a station was not going to appear in Wake County soon, it was disappointing to most people. However, recent developments with E85 in North Carolina could be shared and the prospect of Ethanol as a fuel in NC is still looking promising. At this point, conversations would either end or develop into lengthy discussions. Those that wanted to discuss E85 or other alternatives confirmed my ambition to keep at this project and continue to be encouraged about developing alternative fuels in this area.

Summary

Overall, this survey adequately helped to answer the three questions posed at the outset of the task. It showed that most flex-fueled vehicle owners are not aware that they can use an alternative fuel, but are concerned about the fuel situation and would be willing to try alternatives.

To raise awareness about alternative fuels, and in particular E85, an extensive effort must be made. A phone survey, such as this one, was extremely effective to those that were reached, but too time-consuming to reach the majority. Mailings might be effective in helping owners realize that they own these vehicles, but the majority of the awareness effort must come from the media. Not having a public E85 filing station is a large drawback, and until one is established media coverage will not be fruitful. However, this survey shows that even if a station existed, the majority of flex-fueled owners would not realize that they could fill there. To successfully promote E85, an effort involving media coverage, individual owner notification, and incentives (NEVC's E85 for 85 cents promotion for example) are needed.

Feeding off the publics concerns for publicity is also an effective measure to promote the E85 market. The survey results illustrate the need to focus on reducing the costs for renewable domestic production and promoting the fuel by those assets. Pollution is a small concern and that issue should be addressed and clearly explained in information packets so others don't claim the industry is hiding something. As long as it doesn't pollute more than gasoline, the public will support E85 for it's other benefits.

Both awareness and proven information are necessary to help the public accept E85 as an alternative fuel choice. As shown in this survey, many are willing to try an alternative fuel and consider choosing an alternative fueled vehicle when they buy next, but they want the assurance that it is supported by vehicle manufacturers and fuel distributors. Additionally, cost is a big issue and although vehicle costs are the same, fuel costs are not due to the fuel economy loss. Many in this survey responded that they would be willing to pay more for the alternative fuel, but when it comes down to it many might not be willing to pay more (through direct cost or fuel economy loss), especially if they have to travel to a special location to get it. It is unrealistic to expect E85 at every fueling station, so flex-fueled owners will have to go out of their way to buy it, and equalizing the costs according to fuel economy will encourage many more to use this alternative fuel.

CONCLUSION

Ethanol is a viable alternative fuel that the U.S. and North Carolina can use to displace a portion of our imported nonrenewable petroleum gasoline used for passenger vehicles. Through a review of the economical, operational, environmental, and social views, it can be concluded that we can benefit by using ethanol as a fuel and should continue to research and explore more technology related to this industry.

This does not mean that ethanol is the one solution to our energy crisis, or that it will eliminate all the problems associated with burning a fuel. However, in comparison to our current fuel sources, ethanol is a much better alternative. Too many have drawn negative conclusions about ethanol's use because they treat it as a study only on ethanol or as a comparison to what we might develop in the future, and not on the comparison between ethanol and our current sources of fuel.

Producing ethanol with the current farming practices and a fermentation conversion process that has been modified for efficiency will result in an energy gain, in addition to providing valuable co-products. The agricultural industry is a vital part of our society that in addition to providing food, maintains land that keep our air clean and our landscape green. Ethanol production supports agriculture in our country and is a much needed boost for the farmers that we depend on for our basic needs.

Economically, production and development of the industry has great benefits for the U.S. and the local population with the currently high fuel demand, diminished value of some cash crops such as tobacco, and low agricultural prices due to surplus yields. Subsidies do exist for the ethanol industry. These go to support farmers, who have historically received them, and to the renewable fuel providers. This monetary support is minimal compared to what is given directly and indirectly to the petroleum industry for securing their supply and cleaning up the environmental and social problems created by nonrenewable fuels.

Ethanol will work in a 5% fuel blend for every gasoline vehicle on the road today as an octane booster which helps the fuel burn cleaner and pollute less. Instead of using this soluble chemical that degrades naturally, the majority of the gasoline sold has MTTBE, a potential carcinogenic man-made petroleum derived chemical that will not degrade naturally and finds its way into our groundwater when spilled. In flex-fueled vehicles, a blend of 85% ethanol can be used with no loss in performance characteristics except for lower fuel economy. Even so, every gallon of E85 used will save more than half of a gallon of non-renewable fossil fuel gasoline.

Environmentally, ethanol will be burned in a similar manner as gasoline and some harmful emissions will still be produced. However, results in this study have shown that carbon monoxide levels decreased an average of 50% with E85 as compared to gasoline that was octane enhanced, most probably with MTTBE. If a comparison was performed between E85 and pure gasoline, the results would likely be even more significant. Additionally, with the absorption of carbon by the plants used to make ethanol, the overall contribution of carbon to the atmosphere with ethanol is much less than gasoline, reducing the green house effect.

In general, it was found that ethanol has yet to be socially known or accepted, but the public has concerns about our energy situation and realizes the need for alternative fuels. The awareness survey showed that better and more abundant information needs to reach fuel consumers and alternatives need to be made available for flex-fueled vehicle owners to have a choice. Also, to win support, the Ethanol Industry must be up front about the fuel economy loss and work towards an E85 cost that is 20% less to account for it. Each station that sells E85 should provide information brochures on both benefits and slight disadvantages that come with using the fuel, along with flex-fueled vehicle information. These will create awareness about E85, develop trust by clearly stating the truths, and encourage others to consider buying a flex-fueled vehicle.

No one knows what the future holds for the automobile industry that has for so long depended on a cheap non-renewable resource. It is clear that an alternative must be found if we sustain our current fuel consumption level. Hydrogen and fuel cell cars promise to clean up our ways from our internal combustion engines, but they are not here yet. Hybrid vehicles help to increase miles per gallon, but currently that gallon of fuel is non-renewable. Soon hybrid models may be developed to operate with biofuels instead. Electric vehicles are clean, especially when charged with renewable energy, but are not widely accepted because of their long charging times and limited miles.

Ethanol, however, is usable today in an 85% blend for 4 million vehicles on the road in the U.S. and a 5% blend for all vehicles with no modification to the engine or fueling infrastructure. In ten years, a totally new type of vehicle may be available, but it is more likely that new production and engine technology will be discovered for ethanol that will make it cheaper, easier to produce from various feedstocks, and cleaner burning. Additionally, no one foresees a true replacement that will dominate the fuel industry as petroleum has for the past 60 years. The future of energy and fuels will be a mixture of many different alternative sources. Ethanol has proven to be a viable part of that equation and our future, so we should embrace and expand it as a fuel while improving on its technology along with other alternative fuels.

REFERENCES

1. Taylor, Ray S. “Ethanol: A colorful history, a promising future” 2002 Professional Development Conference, June 2002.

2. Davis, Kelly S. “Corn Milling, Processing, and Generation of Co-products” Minnesota’s Corn Growers Association Technical Symposium, September 2001.

3. American Coalition for Ethanol [www.ethanol.org/pdfs/wetmilling.pdf (29-June-05), 2005.]

4. Kohl, Scott. “Ethanol 101: Overview of Ethanol Production” Ethanol Today, July 2003

5. Ethanol2000. “How Ethanol is made; Detailed diagram of the production process” [www.ethanol2000.com/pics/process_flow.pdf (29-June-05)], 2005.

6. Williams, Jessica. “Beyond Corn” Ethanol Producer Magazine, July 2004.

7. Wallace, Robert and Ibsen, Kelly (NREL), McAloon, Andrew and Yee, Winnie (USDA). “Feasibility Study for Co-Locating and Integrating Ethanol Production Plants from Corn Starch and Lignocellulosic Feedstocks”, National Renewable Energy Laboratory, Jan. 2005.

8. Delta T Corporation. “Evaluation of the Potential for the Production of Lignocellulosic Based Ethanol at Existing Corn Ethanol Facilities”, National Renewable Energy Laboratory, March 2002.

9. Shapouri, Hosein Duffield, James A and Wang, Michael. “The Energy Balance of Corn Ethanol; An update” U.S. Department of Agriculture, July 2002.

10. Nilles, Dave. “A Need for Speed” Ethanol Producer Magazine, August 2004.

11. US Department of Agriculture. “NASS Monthly Ag. Newsletter, June 2005” [www.usda.gov/nass/pubs/nassfact/nf950605.pdf (11-Aug-05)], 2005.

12. CA Transportation Fuels Gasoline, Diesel, Ethanol. “Graph of Ethanol Prices-18 Months” [www.energy.ca.gov/gasoline/graphs/ethanol_18-month.html (11-Aug-05)], 2005.

13. US Grains Council. “Market Perspectives, May 20, 2005” [www.grains.org/buying/market_ perspectives/mp_05-20-05.pdf (11-Aug-05)], 2005.

14. Renewable Fuels Association. “Summary of H.R. 4520: Jumpstart our Business Strength (JOBS) Act” [www.ethanolrfa.org/documents/ArticleforRFA_103104_.pdf(15-Aug-05)], 2005.

15. National Ethanol Vehicle Coalition “E85 Frequently asked Questions; Flex-fueled vehicles” [www.E85fuel.com(29-June-05)], 2005.

16. U.S. Department of Energy, U.S. Environmental Protection Agency. “2003 Fuel Economy Guide” [www.fueleconomy.gov(29-June-05)], 2003.

17. Environmental Protection Agency, “Annual Certification Test Results Report”. [www.epa.gov/otaq/crttst.htm(15-July-05)], 2005.

18. Northeast States for Coordinated Air Use Management, “An Assessment of Options for Reducing MTBE in Reformulated Gasoline”. NESCAUM: Boston, MA. Feb.1998

APPENDICES

Appendix A: Available flex-fueled vehicles

Daimler Chrysler

2005	3.3L V6 Dodge Caravan**, 3.3L V6 Dodge Grand Caravan SE**
2004 – 2005	4.7L V8 Dodge Ram Pickup 1500 Series**
2005	2.7L V6 Dodge Stratus Sedan**, 2.7L V6 Chrysler Sebring Sedan**
2003 – 2004	2.7L V6 Dodge Stratus Sedan, 2.7L V6 Chrysler Sebring Sedan
2003	3.3L V6 Dodge Cargo Minivan, 2.7L V6 Chrysler Sebring Convertible
1998 – 2003	3.3L V6 Dodge Caravan minivan / Chrysler Town & Country minivan
	3.3L V6 Chrysler/Plymouth Voyager minivan,

Ford

2004 – 2005	4.0L V6 Explorer Sport Trac 2WD & 4WD*
2002 – 2005	4.0L V6 Explorer 4WD & 4WD* (4-door)
2004 – 2005	3.0L V6 Taurus sedan and wagon*
1999 – 2003	3.0L V6 Taurus LX, SE and SES sedan*
2001 – 2003	3.0L V6 Supercab Ranger pickup 2WD*
1999 – 2000	3.0L V6 Ranger pickup 4WD and 2WD*
1995 – 1998	3.0L V6 Taurus Sedans*

General Motors

2005	5.3L V8-Vortec Chevy Avalanche*
2003 – 2005	5.3L V8 Chevy Silverado and GMC Sierra half-ton pickups 2WD & 4WD*
2002	5.3L V8 Chevy Silverado and GMC Sierra half-ton pickups 2WD & 4WD
2003 – 2005	5.3L V8-Vortec Chevy Suburban and Tahoe, GMC Yukon and Yukon XLs*
2002	5.3L V8-Vortec Chevy Suburban and Tahoe, GMC Yukon and Yukon XLs
2000 – 2002	2.2L V4 Chevrolet S-10 pickup 2WD, 2.2L V4 Sonoma GMC pickup 2WD

Isuzu

2000 – 2001	2.2L V4 Hombre pickup 2WD

Mazda

2001-2002	3.0L V6 B3000 pickup*
1999	3.0L V6 B3000 pickup*

Mercedes Benz

2004 – 2005	2.6L V6 Mercedes-Benz C240 luxury sedan and wagon 2WD
2005	3.2L V6 Mercedes-Benz C320 sedan and sports coupe 2WD
2004	3.2L V6 Mercedes-Benz C320 sedan, sports coupe and wagon 2WD

Mercury

2002 – 2005	4.0L V6 Mountaineers 2WD & 4WD*
2000 – 2005	3.0L V6 Sables sedan and wagon*

Nissan

2005	5.6L V8 Titan Truck 2WD & 4WD*

*Selected Vehicles: Check VIN identification number
**Fleet Vehicle only

Appendix A: VIN information for flex-fueled vehicles

Selected flex-fueled vehicles that can not be identified as such by a decal on the fuel door may still be E85 compatible if their VIN number matches the below characters. Always check the owners manual as well to verify if your vehicle might be flex-fueled and how to identify it as so.

Ford Motor Company^		
Vehicle	**Characters 2 - 3**	**Character 8**
Taurus	FA	2
Mercury Sable	ME	2
Ranger	FT	V
Explorer	FM	K
Mercury Mountaineer	M2	K

General Motors^		
Vehicle	**Characters 2 - 3**	**Character 8**
Chevy S-10 Pickup	GC	5
Sierra	GT	Z
Silverado	GC	Z
GMC Sonoma	GT	5
Suburban	GC	Z
Tahoe	GC	Z
Yukon & Yukon XL	GT	Z
Avalanche		Z

DaimlerChrysler^		
Vehicle	**Characters 2 - 3**	**Character 8**
Chrysler Sebring	C3	T
Chrysler Town & Country	C4	G or 3
Dodge Caravan	B4	G or 3
Dodge Cargo Minivan	B4 or B8	3
Dodge Ram 1500		P
Dodge Stratus	B3	T
Plymouth Voyager	P4	G or 3

Mazda^		
Vehicle	**Characters 2 -3**	**Character 8**
B3000 Pickup	F2	V

^ This information is the most accurate information available through the National Ethanol Vehicle Coalition [www.E85Fuel.com].

Appendix B: Vehicle specifications - 2004 Chevrolet Tahoe

DIMENSIONS

Exterior

Length: 198.8 in.
Width: 78.8 in.
Height: 76.7 in.
Wheel Base: 116 in.
Ground Clearance: 8.4 in.
Curb Weight: 5262 lbs.
Gross Weight: 6900 lbs.

Interior

Front Head Room: 40.7 in.
Front Hip Room: 61.4 in.
Front Shoulder Room: 65.2 in.
Rear Head Room: 39.4 in.
Rear Shoulder Room: 65.1 in.
Rear Hip Room: 61.3 in.
Front Leg Room: 41.3 in.
Rear Leg Room: 38.6 in.
Luggage Capacity: 16.3 cu. ft.
Maximum Cargo Capacity: 105 cu. ft.
Maximum Seating: 8

PERFORMANCE DATA

Base Number of Cylinders: 8
Base Engine Size: 5.3 liters
Base Engine Type: V8
Horsepower: 295 hp
Max Horsepower: 5200 rpm
Torque: 330 ft-lbs.
Max Torque: 4000 rpm
Maximum Payload: 1538 lbs.
Maximum Towing Capacity: 7800 lbs.
Drive Type: 4WD
Turning Circle: 38.3 ft.

FUEL DATA

Fuel Tank Capacity: 26 gal.
EPA Mileage Estimates: (City/Highway)
Automatic: : 14 mpg / 18 mpg
Range in Miles: (City/Highway)
Automatic: 364 mi. / 468 mi.

1st 8 VIN Numbers: 1**GN**EK13**Z**

Mileage: ~ 11,000

Appendix B: Vehicle specifications - 2005 Dodge Caravan

DIMENSIONS

Exterior

Length: 200.5 in.
Width: 78.6 in.
Height: 68.8 in.
Wheel Base: 119.3 in.
Ground Clearance: 5.4 in.
Curb Weight: 4146 lbs.

Interior

Front Head Room: 39.6 in.
Front Hip Room: 57.2 in.
Front Shoulder Room: 62.9 in.
Rear Head Room: 39.1 in.
Rear Shoulder Room: 64.8 in.
Rear Hip Room: 67.5 in.
Front Leg Room: 40.6 in.
Rear Leg Room: 34.7 in.
Luggage Capacity: 19.8 cu. ft.
Maximum Cargo Capacity: 168 cu. ft.
Maximum Seating: 7

PERFORMANCE DATA

Base Number of Cylinders: 6
Base Engine Size: 3.3 liters
Base Engine Type: V6
Horsepower: 180 hp
Max Horsepower: 5200 rpm
Torque: 210 ft-lbs.
Max Torque: 4000 rpm
Maximum Towing Capacity: 2000 lbs.
Drive Type: FWD
Turning Circle: 39.4 ft.

FUEL DATA

Fuel Tank Capacity: 20 gal.

EPA Mileage Estimates: (City/Highway)
Automatic: : 19 mpg / 26 mpg

Range in Miles: (City/Highway)
Automatic: 380 mi. / 520 mi.


1st 8 VIN Numbers: 1**D4**GP25**E**

Mileage: ~ 12,000

Appendix B: Vehicle specifications - 2004 Ford Taurus

DIMENSIONS

Exterior

Length: 197.6 in.
Width: 73 in.
Height: 55.5 in.
Wheel Base: 108.5 in.
Curb Weight: 3306 lbs.

Interior

Front Head Room: 40 in.
Front Hip Room: 54.4 in.
Front Shoulder Room: 57.3 in.
Rear Head Room: 38.1 in.
Rear Shoulder Room: 56.6 in.
Rear Hip Room: 55.7 in.
Front Leg Room: 42.2 in.
Rear Leg Room: 38.9 in.
Luggage Capacity: 16 cu. ft.
Maximum Cargo Capacity: 16 cu. ft.
Maximum Seating: 6

PERFORMANCE DATA

Base Number of Cylinders: 6
Base Engine Size: 3 liters
Base Engine Type: V6
Horsepower: 155 hp
Max Horsepower: 4900 rpm
Torque: 185 ft-lbs.
Max Torque: 3900 rpm
Maximum Towing Capacity: 1250 lbs.
Drive Type: FWD
Turning Circle: 39.7 ft.

FUEL DATA

Fuel Tank Capacity: 18 gal.

EPA Mileage Estimates: (City/Highway)
Automatic: : 19 mpg / 27 mpg

Range in Miles: (City/Highway)
Automatic: 342 mi. / 486 mi.

1st 8 VIN Numbers: 1**FA**FP52**2**

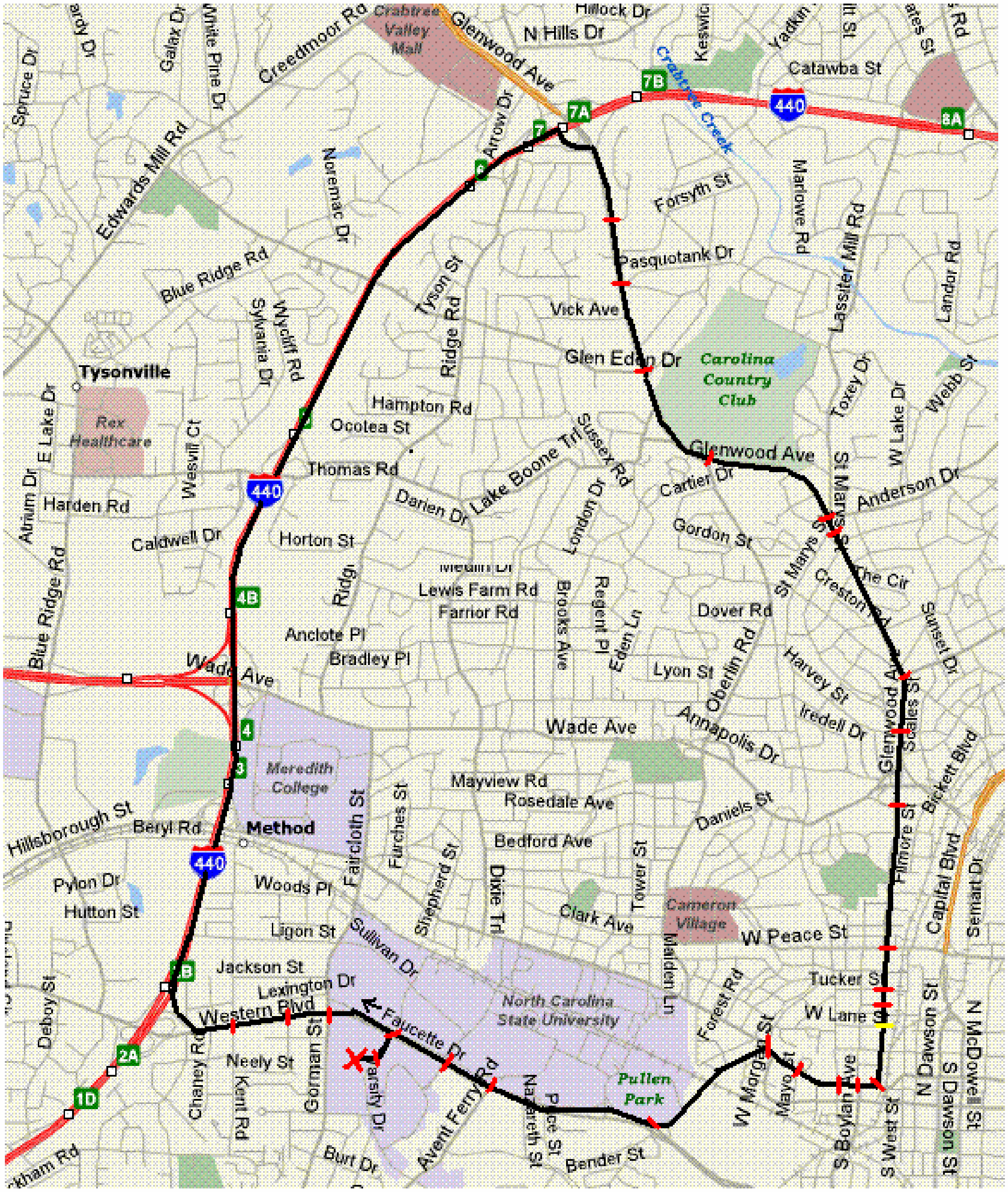
Mileage: ~ 30,000

Appendix C: Route for E85 emissions testing

	Maneuvers	Distance
0:	Parking Lot to STOP on VARSITY ST. *Gravel lot 10 mph*	0.1 miles
1:	Go left (NORTH) on VARSITY ST. toward WESTERN BLVD. *city street 35 mph*	0.1 miles
2:	Turn LEFT onto WESTERN BLVD. *divided arterial 45 mph*	0.9 miles
3:	Merge onto I-440 N/US-1 N. *divided highway 60 mph*	4.0 miles
4:	Merge onto GLENWOOD AVE/NC-50 S/US-70 E via EXIT 7. *divided highway 45 mph*	1.6 miles
5:	Continue SOUTH at OBERLIN RD. on GLENWOOD AVE *divided arterial 35 mph*	2.4 miles
6:	Continue SOUTH at PEACE ST. on GLENWOOD AVE *city street 35 mph*	0.5 miles
7:	Turn RIGHT onto HILLSBOROUGH ST/NC-54. *divided arterial 35 mph*	0.6 miles
8:	Turn LEFT onto ASHE AVE. *city avenue 25 mph (0.2) and 35 mph (0.3)*	0.5 miles
9:	Turn SLIGHT RIGHT onto WESTERN BLVD. *divided arterial 45 mph*	1.2 miles
10:	Turn LEFT onto VARSITY ST. *city street 35 mph*	0.1 miles
11:	Turn RIGHT into McKimmon Parking AFV Garage entrance *parking lot / dirt driveway 10 mph*	0.1 miles

Total Est. Time: 25 minutes Total Est. Distance: 12.1 miles

Appendix C: Testing route with indicated stops



▬ Route Traveled

✕ Start / Finish

Stops (Traffic light or stop sign)

Flashing yellow light

Appendix D: Wake County flex-fueled vehicle data

Original List Total **9,404**

Wrong Info

From Other States 102

1991-95 Silverados 204

Non-Wake Cities 251

Modified List Total **8,847**

Private 6,423 73%

Commercial 2,424 27%

	Total		Private			Commercial			Population	
By City Address	**#**	**%**	**#**	**% of City**	**% of Total**	**#**	**% of City**	**% of Total**	**Est.**	**Ratio FFV / pop**
Apex	567	6%	522	92%	8%	45	8%	2%	36,580	0.016
Cary	1,080	12%	964	89%	15%	116	11%	5%	137,020	0.008
Fuquay Varina	290	3%	250	86%	4%	40	14%	2%	13,640	0.021
Garner	283	3%	209	74%	3%	74	26%	3%	27,280	0.010
Holly Springs	200	2%	193	97%	3%	7	4%	0%	17,360	0.012
Knightdale	169	2%	146	86%	2%	23	14%	1%	11,160	0.015
Morrisville	143	2%	108	76%	2%	35	24%	1%	15,500	0.009
New Hill	6	0%	6	100%	0%	0	0%	0%	620	0.010
Raleigh	5,265	60%	3,283	62%	51%	1,982	38%	82%	417,880	0.013
Rolesville	23	0%	21	91%	0%	2	9%	0%	1,364	0.017
Wake Forest	469	5%	411	88%	6%	58	12%	2%	21,080	0.022
Wendell	143	2%	119	83%	2%	24	17%	1%	5,580	0.026
Willow Springs	70	1%	64	91%	1%	6	9%	0%	4,500	0.016
Zebulon	139	2%	127	91%	2%	12	9%	0%	5,580	0.025
Totals	**8,847**		**6,423**			**2,424**			**715,144**	**0.0124**

	Total		Private			Commercial		
By Vehicle Type	**#**	**%**	**#**	**% of Type**	**% of Total**	**#**	**% of Type**	**% of Total**
Chrysler Sebring	58	1%	42	72%	1%	16	28%	1%
Chrysler Stratus	461	5%	36	8%	1%	425	92%	18%
Ford Taurus	717	8%	159	22%	2%	558	78%	23%
Dodge Caravan	927	10%	882	95%	14%	45	5%	2%
Plymouth Voyager	567	6%	549	97%	9%	18	3%	1%
Chrysler Town & Country	188	2%	183	97%	3%	5	3%	0%
Chevrolet S-10	427	5%	345	81%	5%	82	19%	3%
Ford Ranger	316	4%	206	65%	3%	110	35%	5%
Mazda Pickup	17	0%	16	94%	0%	1	6%	0%
Chevrolet Sonoma	74	1%	65	88%	1%	9	12%	0%
Chevrolet Silverado	59	1%	15	25%	0%	44	75%	2%
Chevrolet Tahoe	2,347	27%	1,771	75%	28%	576	25%	24%
GMC Yukon	775	9%	659	85%	10%	116	15%	5%
Ford Explorer	338	4%	280	83%	4%	58	17%	2%
Chevrolet Suburban	1,576	18%	1,215	77%	19%	361	23%	15%
Totals	**8,847**		**6,423**			**2,424**		

Appendix D: Wake County flex-fueled vehicle data

Significant Fleets

NCDOA; TEMP-RALEIGH1 (MOTOR POOL)*	220 E. Peace St., Raleigh	207
P V HOLDING CORP	1016 Rental Car Rd., Raleigh	150
TRIANGLE RENT A CAR INC	4817 Hargrove Rd., Raleigh	123
NCDOA; NCSU-N C STATE UNIVERSITY	NC State University, Raleigh	80
HERTZ VEHICLES LLC	1017 Rental Car Rd., Raleigh	65
PRINCE TELECOM HOLDINGS INC	1425 Mechanical Blvd., Garner	37
NCDOA; DOT-HWY (LOC & SURVEY)	1020 Birch Ridge Dr., Raleigh	35
NCDOA; DOT-HWY (GEOTECHNICAL UNIT)*	1589 Mail Service Center, Raleigh	30
CAROLINA POWER & LIGHT CO	411 Fayetteville St., Raleigh	29
NCDOA; ADM-MAIL SERVICE CTR	3905 Reedy Creek Rd., Raleigh	27
NCDOA; CORR-CORRECTION	2020 Yonkers Rd., Raleigh	25
NCDOA; HHS-FACILITY SERVICES*	2711 Mail Service Center, Raleigh	22
NCDOA; ENR-ENVIRON & NAT RES	3800 Barret Dr., Raleigh	20
NCDOA; HHS-OES-GOV. MOREHEAD SCHOOL	301 Ashe Ave., Raleigh	20
RENTAL CAR FINANCE CORP	1009 Rental Car Dr., Raleigh	17
NCDOA; CORR-PRISONS	831 W. Morgan St., Raleigh	17
CROSSROADS FORD INC	1101 Buck Jones Rd., Raleigh	15
MIMS DISTRIBUTING CO INC	2100 Harrod St., Raleigh	15
NCDOA; DOT-HWY MAT.& TEST	1801 Blue Ridge Rd., Raleigh	15
NCDOA; HHS-FACILITY SERVICES	701 Barbour Dr., Raleigh	15
NCDOA; NCSU-AGR EXTENSION SER	NC State University, Raleigh	15
WEATHER MASTER HEAT & AIR	305 Village Dr., Knightdale	12
NCDOA; CCPS-NATIONAL GUARD	4105 Reedy Creek Rd., Raleigh	12
NCDOA; CORR-COMMUNITY CORRECTIONS	320 S Salisbury St., Raleigh	12
NCDOA; TEMP-RALEIGH(VEH ASSIGNMENT)*	1308 Mail Service Center, Raleigh	12
CITY OF RALEIGH	1014 N West St., Raleigh	11
WAKE COUNTY	401 Capital Blvd., Raleigh	8

*Location of a current State owned E85 filling station

Appendix E: Fuel economy testing calculations

2004 Ford Taurus

Gasoline: 411 miles / 18.5 gallons = 22.2 mpg

E85: 300 miles / 18.5 gallons = 16.2 mpg

Worst Case E85: 2 gallons of gasoline @ 22.2 mpg = 44.4 miles

300 miles – 44.4 miles = 255.6 miles

255.6 / (18.5 – 2 gallons) = 15.5 mpg

Fuel Economy Drop: (22.2 – 16.2) / 22.2 = **27.0%**
to
(22.2 – 15.5) / 22.2 = **30.2%**

2005 Dodge Caravan

Gasoline: 421 miles / 20.5 gallons = 20.5 mpg

E85: 346 miles / 20.5 gallons = 16.9 mpg

Worst Case E85: 4 gallons of gasoline @ 20.5 mpg = 82 miles

346 miles – 82 miles = 264 miles

264 / (20.5 – 4 gallons) = 16.0 mpg

Fuel Economy Drop: (20.5 – 16.9) / 20.5 = **17.6%**
to
(20.5 – 16.0) / 20.5 = **22.0%**

2004 Chevrolet Tahoe

Gasoline: 404 miles / 26.5 gallons = 15.2 mpg

E85: 307 miles / 26.5 gallons = 11.6 mpg

Worst Case E85: 1.5 gallons of gasoline @ 15.2 mpg = 22.8 miles

307 miles – 22.8 miles = 284.2 miles

284.2 / (26.5 – 1.5 gallons) = 11.4 mpg

Fuel Economy Drop: (15.2 – 11.6) / 15.2 = **23.7%**
to
(15.2 – 11.4) / 15.2 = **25.0%**

Appendix F: Wake County usage calculations

	Wake County Data		2003 Model Year Info				Overall Averages 45% Hwy, 55% City		
			Gasoline		E85				
Vehicle Type	**# of FFVs**	**% of FFVs**	**Hwy**	**City**	**Hwy**	**City**	**Gas**	**E85**	**Fuel Economy Decrease**
Chrysler Sebring	58	0.7%	21	28	16	20	24.9	18.2	26.8%
Chrysler Stratus	461	5.2%	21	28	16	20	24.9	18.2	26.8%
Ford Taurus	717	8.1%	19	27	14	20	23.4	17.3	26.1%
Dodge Caravan	927	10.5%	19	26	13	17	22.9	15.2	33.5%
Plymouth Voyager	567	6.4%	18	25	13	18	21.9	15.8	27.9%
Chrysler Town & Country	188	2.1%	18	25	13	17	21.9	15.2	30.4%
Chevrolet S-10	427	4.8%	21	27	15	20	23.8	17.5	26.6%
Ford Ranger	316	3.6%	17	21	13	16	19.2	14.7	23.7%
Mazda Pickup	17	0.2%	17	21	13	16	19.2	14.7	23.7%
GMC Sonoma	74	0.8%	21	27	15	20	23.8	17.5	26.6%
Chevrolet Silverado	59	0.7%	14	18	11	13	16.2	11.9	26.7%
Chevrolet Tahoe	2,347	26.5%	14	18	10	13	16.4	12.0	26.9%
GMC Yukon	775	8.8%	14	18	10	13	16.2	11.7	28.1%
Ford Explorer	338	3.8%	15	21	11	16	18.3	13.5	26.4%
Chevrolet Suburban	1,576	17.8%	14	18	10	13	16.2	11.7	28.1%
	8,847	Averages based on % of FFVs :					**19.1**	**13.8**	**27.9%**

Assumptions:

885 E85 Users – 10% of the total Wake County FFV population

7,500 average miles per year run on E85 by these users (50% of 15,000 ave.)

Calculations:

E85 Usage;

885 users * 7,500 miles per year = 6,640,000 E85 miles per year

6,640,000 miles / 13.8 E85 mpg = 480,000 gallons of E85 per year

Reasonability check;

480,000 gallons per year / 365 days per year = 1,300 gallons per day

1,300 gallons per day / 15 gallons per fill-up = 87 fill-ups per day

87 fill-ups per day / 12 hours = 7-8 costumers per hour

Fossil Fuel Savings;

6,640,000 miles per year / 19.1 Gas mpg = 350,000 gallons

480,000 gallons per year of E85 * 15% gasoline in E85 = 72,000 gallons

350,000 gallons – 72,000 gallons = **278,000 gallons of gasoline per year**

Appendix G: Personal Diagnostic Assistant emissions analyzer data sheet

Comprehensive Engine Analysis in the Palm of your Hand™

PDA4GBD / PDA5GBD Emissions Analyzer

PRODUCT CONTENTS LIST FOR GAS BENCH WITH DISPLAY:
Standard product contents, 4 or 5 gas emissions analyzer, 12V battery adapter lead, hose kit, **PDA4GBD/PD5GBD** user's manual, (2) replacement filters, AC Adapter and Sync. probe and extension for measuring RPM.

System Features

- Designed for portable (on-the-road) and stationary emissions testing
- Completely portable automotive emissions diagnostics and enhanced emission testing
- Meets or exceeds BAR-97, OIML Class 0 and Class 1 gas measurement bias and accuracy
- Live emission or integrated display data through PDA2100A, PDA2050A or PDA2050
- Live emission data through PC or Laptop interface
- Fast warm-up time (less than one minute)
- Lightweight and small in size
- Switch between gas data and engine diagnostic features
- Operates off vehicle battery or AC adapter
- Large screen displays up to 8 panels or 8 Histographs of data at a time
- Save screens as reports (up to 30)
- Save up to 8 replay files (up to 30 min. each)
- Displays all gases, AFR or Lambda and RPM
- Displays gas reading in % of volume or grams per mile
- Easy access to replaceables - filters and sensors

System Specifications

One of the most effective engine analysis tools available.
Display Specifications:

- HC: 0 to 9999 PPM (Hexane) 0-300
- CO: 0 to 10% 0-1000
- CO2: 0 to 20% 0-10000
- O2: 0 to 21%
- NOx: 0 to 4000 ppm (PDA5GBA) 0-300
- RPM: 0-9999 RPM
- Meter: Volts, current, duty cycle, frequency and user programmable probes
- 4 Gas meter with RPM and auxiliary input measurement
- Min/max keeps track of test data
- Displays live engine emissions in the shop bay or on the road
- Screens can be stored for uploading to PC or direct printing of reports
- 5 Gas running histograph with AFR, RPM and auxiliary input
- Auto ranging for best display
- Graphs scroll to left when filled
- Can record up to 30 minutes for later replay
- Replay of 5-Gas running histograph and meter file
- Full cursor function with digital readouts
- Continuous recording, no lost data points
- Performs on the road or in the bay ™

Appendix G: Personal Diagnostic Assistant emissions analyzer data sheet (con't)

Accuracy
• HC: 4 ppm
• CO: 0.02%
• CO2: 0.3%
• O2: 0.1%
• NOx: NOx: 0 to 4,000 ppm (25ppm)
4,001 to 5,000 ppm (+-5% rel.)
• Response time: Time to measure 90% of full scale is 4 sec (T90 = 4 sec)

Resolution
• HC: 1 ppm
• CO: 0.001 vol.%
• CO2
: 0.01 vol. %
• O2: 0.01 vol. %
• NOx: 1 ppm
• Flow rate: 0.3 to 3.0 liters/min
• RPM .5%

Power Requirements
• 12 VDC
• 1 Amp typical, 5 Amps max
• 12 Watts typical

Physical Dimensions
• Length: 12"/30 cm
• Width: 11.5"/29 cm
• Height: 6"/15 cm
• Weight: less than
12 lb./5.45kg

System Transport Time
Less than 5 seconds for - HC, CO and CO2
Less than 5 seconds for NOx and O2

Typical engine conditions detected from tailpipe readings

HC	CO	CO2	O2	NOx	Possible Cause
H	L	L	H	L	Excessively lean condition
H	L	H	H	H	Moderately lean condition
L	L	L	H	L	Exhaust leak
H	H	L	L	L	Rich mixture
H	H	L	H	L	Rich mixture with misfire

Additional PDA Products Available

• **PDA2100A**
(Complete hand held engine analyzer)
• **PDA2050A**
(Hand held 4 channel lab scope/ multimeter with ignition analysis feature)
• **PDW/PDWPC**
(Personal Diagnostic Workstations - configured to your needs and budget)
• **PDAECVu**
(ECM analyzer for domestic vehicles 83-95)
• **PST500 OBDII scantool**
• **Multi-Language**
Software supports different foreign languages
• **PC gas software**
Interro's emission analyzers can be connected directly to a shop PC or a laptop for detailed, in bay, emission analysis and testing.

For Demonstration or more information contact:

INTERRO SYSTEMS, INC.,1338 Bordeaux Drive Sunnyvale, CA 94089-1005, Phone: (408) 548-0580, Fax: (408) 548-0589, Tech. Support: (800) 434-6744 e-mail: sales@interro.com, Web-site:- www.interro.com

Appendix H: Sample time sheet for an emissions testing run

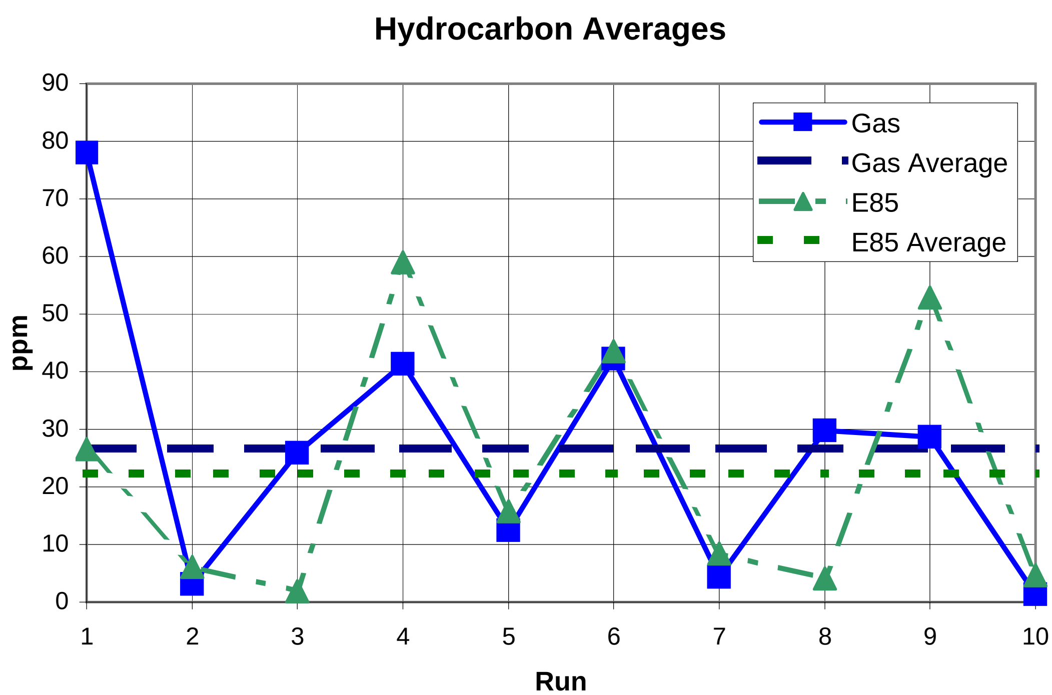
Date: *6/8/05* Conditions: *Sunny, humid, damp roads*
Time: *10:35* ***E85 Run 6*** Temperature: *80 F*
Vehicle: *Tahoe* Vehicle Driving: no cruise, fan med, windows up
Fuel: *E85* Start Procedure: 5 min engine/equipment warm up

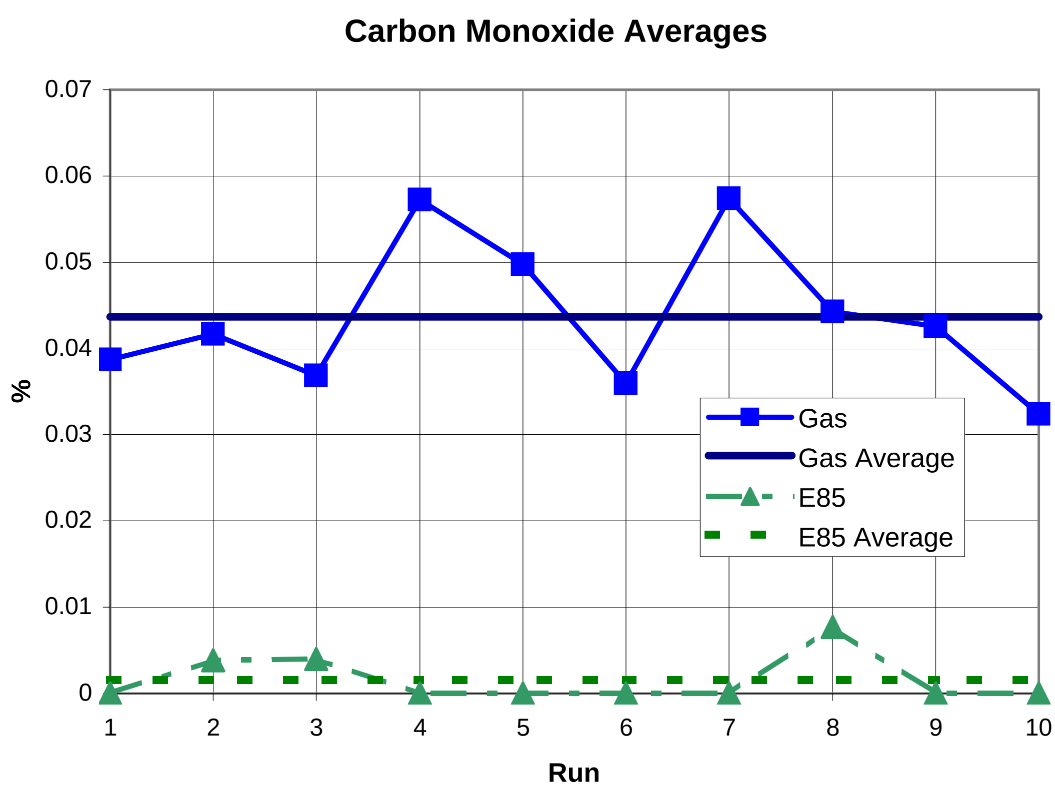
#	Intersection	Stop	Slow	Comment Start: 34
1	McKimmon Center / Varsity	X		Left Turn
2	Varsity / Western	X		Left Turn; Hard Acceleration
3	Western / Gorman	X		35
4	Western / Whitmore			
5	Western / Method			
6	Western / 440		X	20 mph On ramp
7	440 / Glenwood		X	35 mph Off ramp
8	Glenwood / Womens Club			
9	Glenwood / Pasquotank	X		Reset PDA 41
10	Glenwood / Granville			
11	Glenwood / Oberlin	X		43
12	Glenwood / Anderson	X		45
13	Glenwood / Byrd			
14	Glenwood / W Whitaker	X		46
15	Glenwood / Harvey			
16	Glenwood / Cole			
17	Glenwood / Peace	X		48
18	Glenwood / Tucker		X	10 mph
19	Glenwood / North			
20	Glenwood / W. Jones		X	10 mph
21	Glenwood / Hillsborough		X	Right Turn 15 mph
22	Hillsborough / Boylan	X		Reset PDA 50
23	Hillsborough / St. Marys			
24	Hillsborough / Mayo			
25	Hillsborough / Ashe	X		Left Turn 51
26	Ashe / Western	X		Right Turn; Hard Acceleration 53
27	Western / Avent Ferry			
28	Westen / Dan Allen			
29	Western / Varsity		X	Left Turn 20 mph
30	Varsity / McKimmon		X	Right Turn 15 mph End: 56

Appendix I: Emission test results - 2004 Ford Taurus

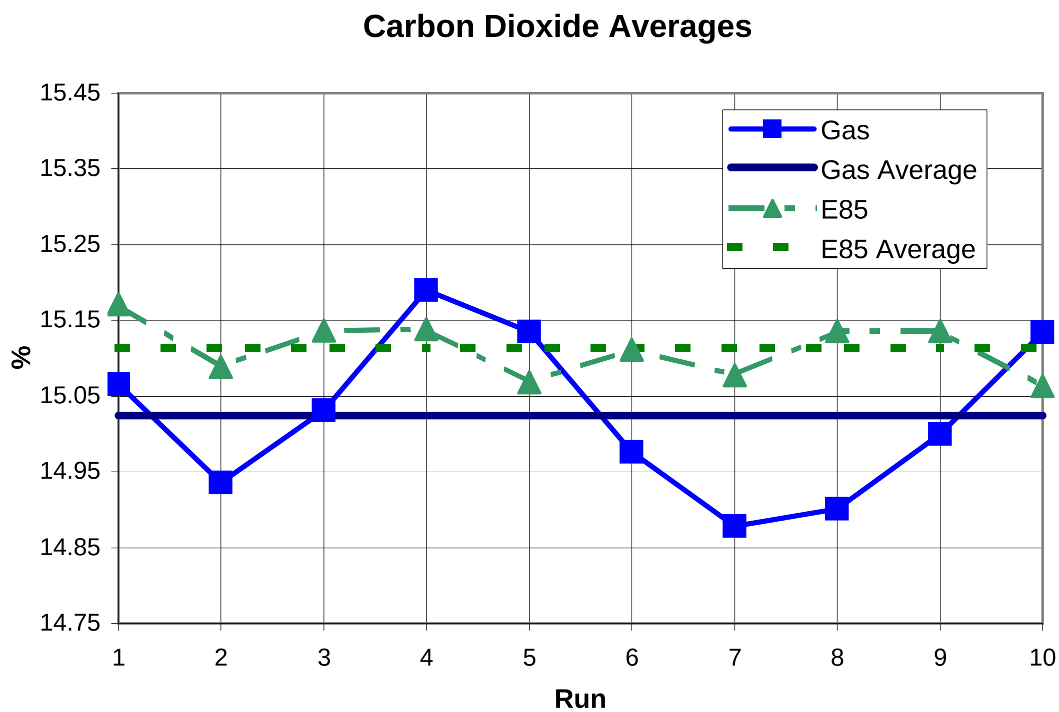
Averages			Run 0	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
HC	ppm	Gas	78	3	26	41	12	42	4	30	29	1
		Gas Ave.	27	27	27	27	27	27	27	27	27	27
		E85	27	6	2	59	16	44	8	4	53	5
		E85 Ave.	22	22	22	22	22	22	22	22	22	22
CO	%	Gas	0.04	0.04	0.04	0.06	0.05	0.04	0.06	0.04	0.04	0.03
		Gas Ave.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
		E85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
		E85 Ave.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	%	Gas	15.1	14.9	15.0	15.2	15.1	15.0	14.9	14.9	15.0	15.1
		Gas Ave.	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
		E85	15.2	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
		E85 Ave.	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Nox	ppm	Gas	20	17	27	22	19	19	33	30	19	20
		Gas Ave.	23	23	23	23	23	23	23	23	23	23
		E85	18	19	20	23	23	29	20	15	15	17
		E85 Ave.	20	20	20	20	20	20	20	20	20	20
O2	%	Gas	0.08	0.11	0.07	0.07	0.10	0.07	0.10	0.09	0.11	0.08
		Gas Ave.	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
		E85	0.10	0.15	0.07	0.07	0.29	0.04	0.22	0.05	0.07	0.16
		E85 Ave.	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
AFR		Gas	14.7	12.3	14.7	14.7	14.5	14.7	11.6	14.8	14.7	9.3
		Gas Ave.	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6
		E85	14.8	14.9	10.8	14.7	14.8	14.7	14.7	14.4	14.7	14.7
		E85 Ave.	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
RPM		Gas	2679	2744	2835	2889	2823	2759	2719	2606	2720	2870
		Gas Ave.	2764	2764	2764	2764	2764	2764	2764	2764	2764	2764
		E85	2871	2827	2760	2741	2634	2635	2621	2591	2928	2798
		E85 Ave.	2741	2741	2741	2741	2741	2741	2741	2741	2741	2741
Mass Calculations			Run 0	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
HC	gm/mi	Gas	0.40	0.02	0.14	0.21	0.06	0.22	0.02	0.14	0.15	0.01
		Gas Ave.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
		E85	0.19	0.05	0.01	0.41	0.11	0.31	0.06	0.03	0.37	0.03
		E85 Ave.	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
CO	gm/mi	Gas	0.66	0.66	0.61	0.98	0.83	0.61	0.96	0.74	0.65	0.53
		Gas Ave.	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
		E85	0.02	0.06	0.07	0.02	0.02	0.00	0.01	0.15	0.02	0.06
		E85 Ave.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
CO2	gm/mi	Gas	395	395	395	395	395	395	395	395	395	396
		Gas Ave.	395	395	395	395	395	395	395	395	395	395
		E85	543	543	543	543	543	543	543	543	543	543
		E85 Ave.	543	543	543	543	543	543	543	543	543	543
Nox	gm/mi	Gas	0.06	0.05	0.08	0.06	0.05	0.05	0.09	0.08	0.05	0.06
		Gas Ave.	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
		E85	0.07	0.08	0.07	0.09	0.08	0.11	0.07	0.06	0.06	0.07
		E85 Ave.	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

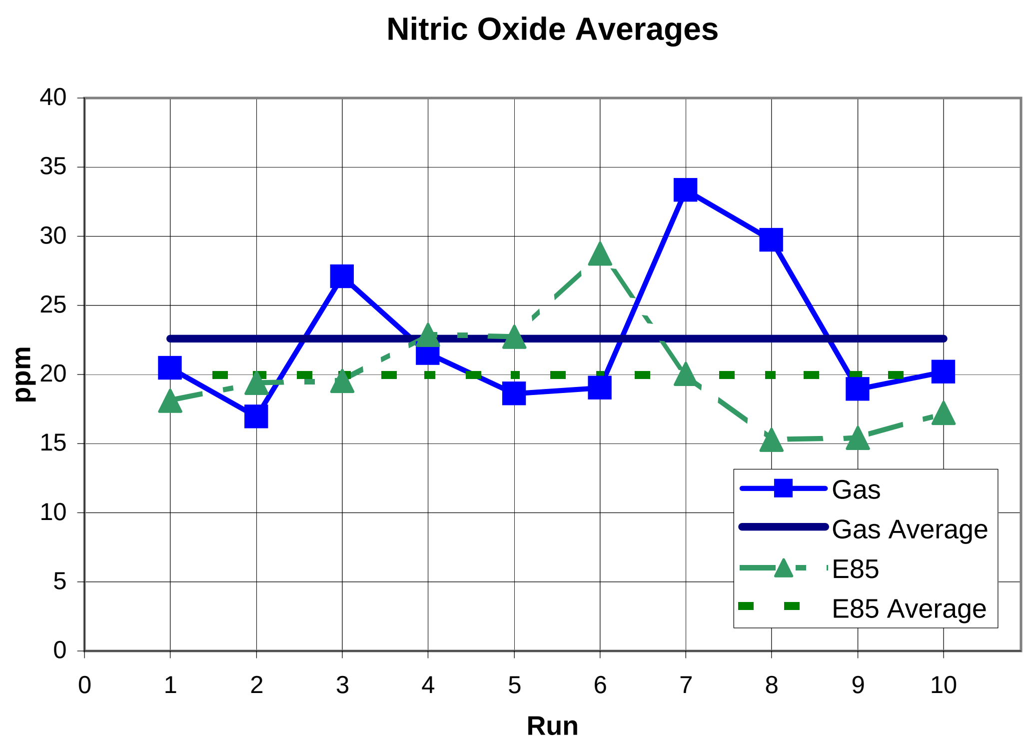
Appendix I: Emission test results - 2004 Ford Taurus (con't)



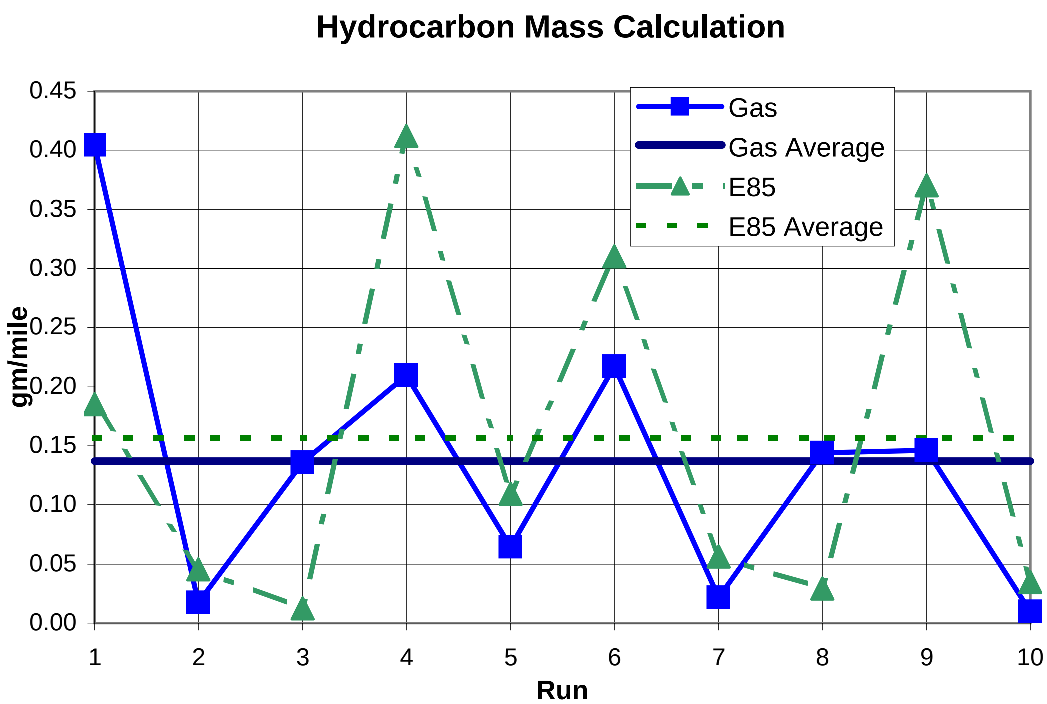


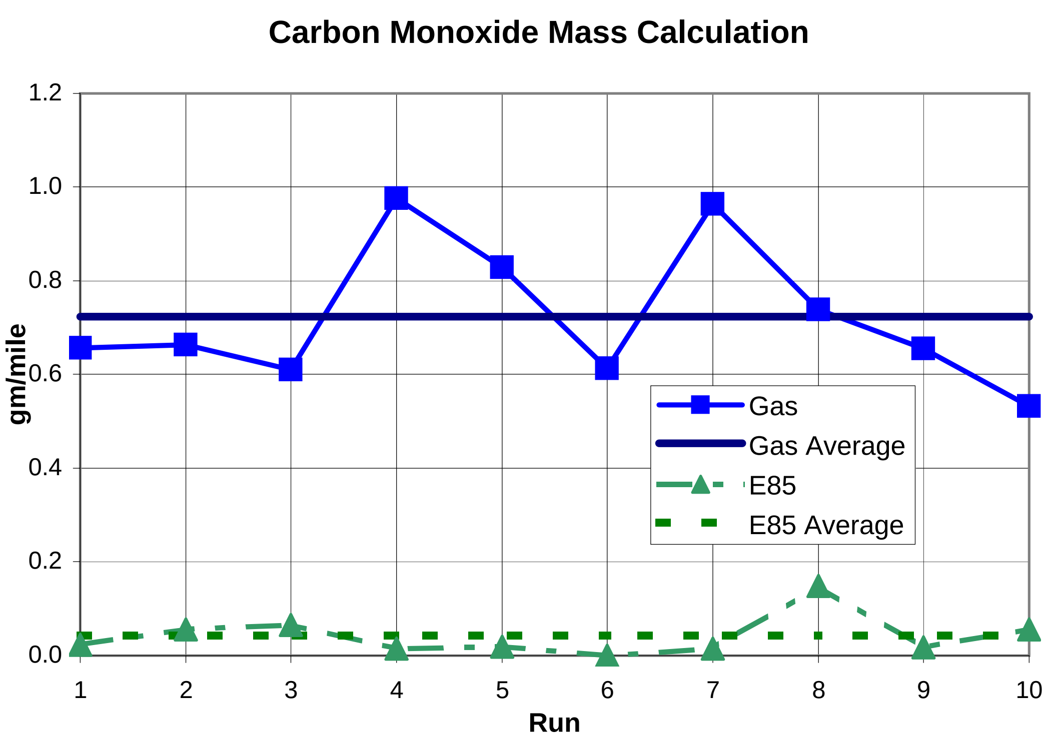
Appendix I: Emission test results - 2004 Ford Taurus (con't)



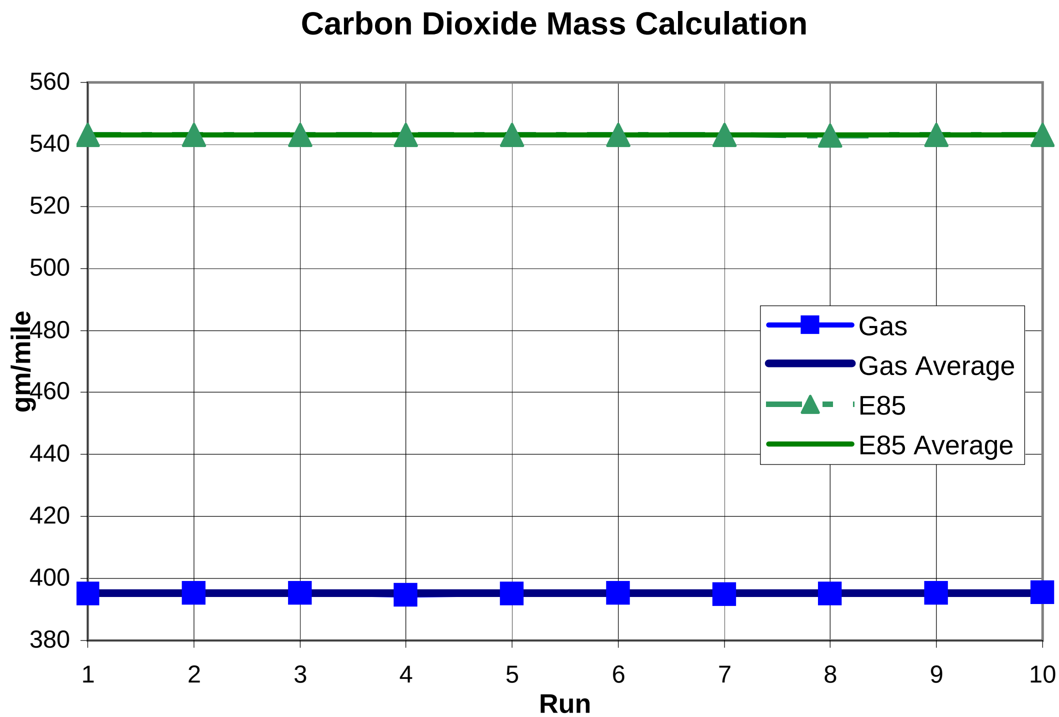


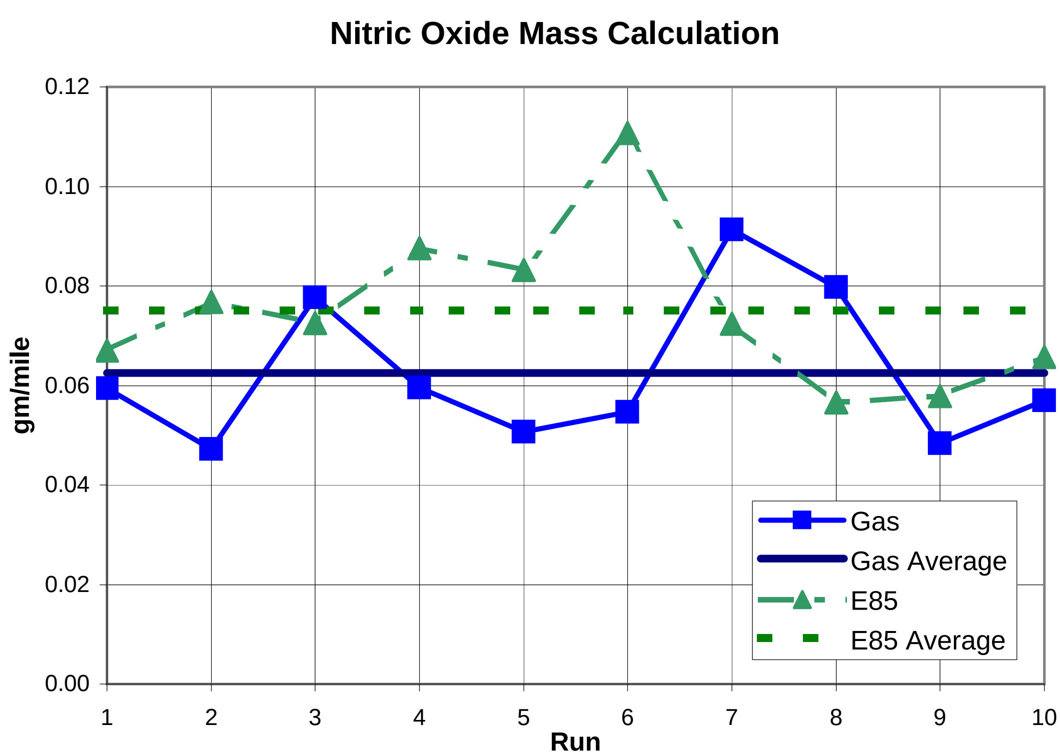
Appendix I: Emission test results - 2004 Ford Taurus (con't)





Appendix I: Emission test results - 2004 Ford Taurus (con't)

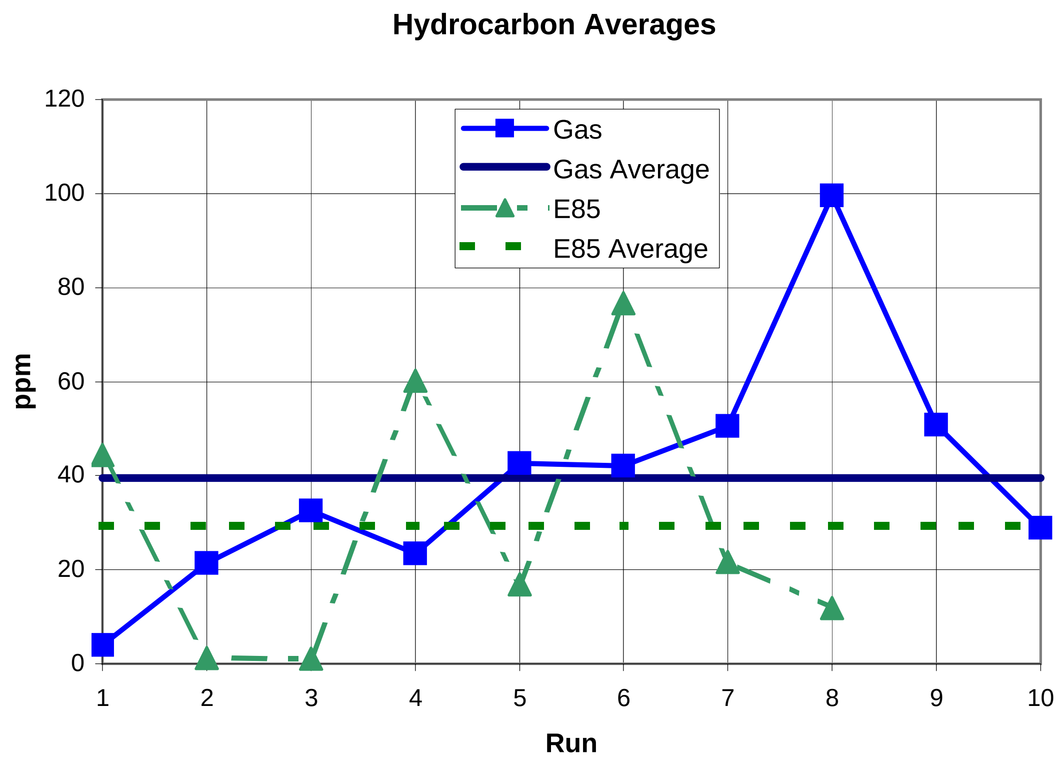


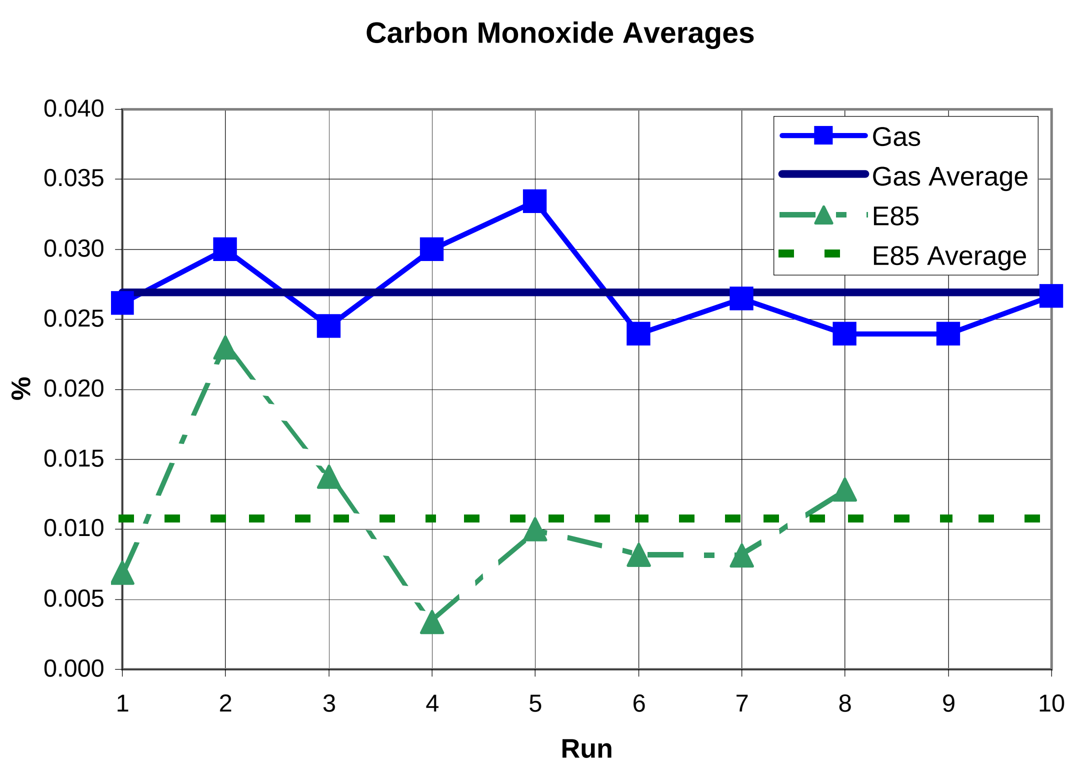


Appendix J: Emission test results - 2005 Dodge Caravan

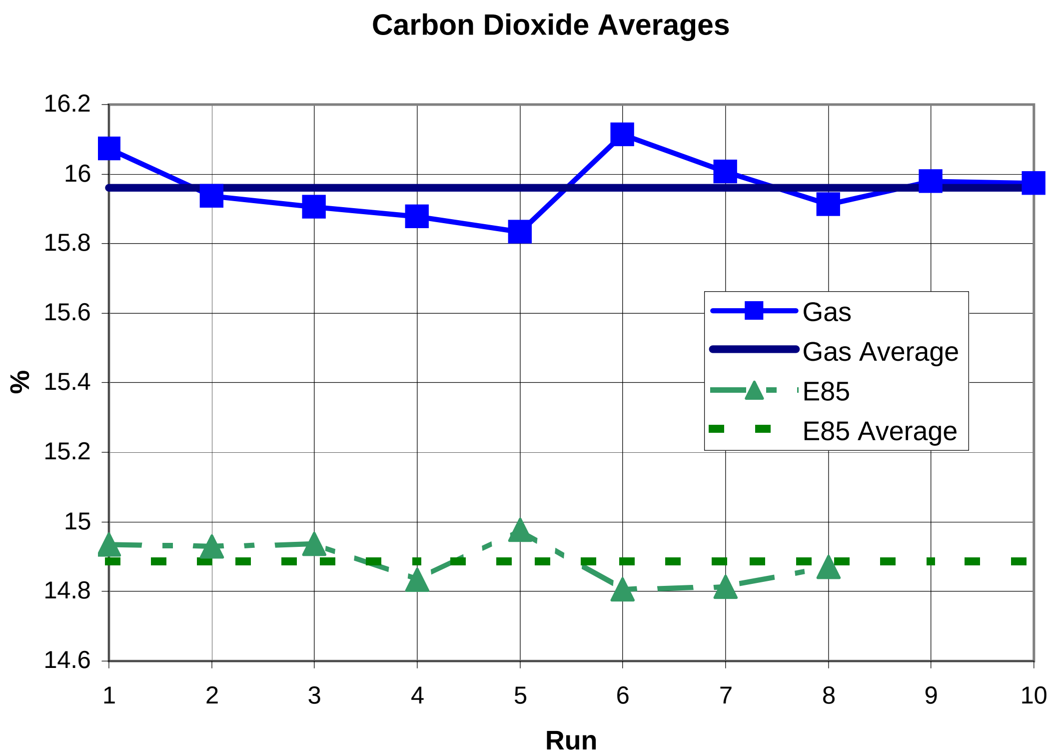
Averages			Run 0	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
HC	ppm	Gas	4	21	33	23	43	42	51	100	51	29
		Gas Ave.	40	40	40	40	40	40	40	40	40	40
		E85	44	1	1	60	17	77	22	12	71	28
		E85 Ave.	29	29	29	29	29	29	29	29	29	29
CO	%	Gas	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.02	0.02	0.03
		Gas Ave.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
		E85	0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00
		E85 Ave.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CO2	%	Gas	16.1	15.9	15.9	15.9	15.8	16.1	16.0	15.9	16.0	16.0
		Gas Ave.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
		E85	14.9	14.9	14.9	14.8	15.0	14.8	14.8	14.9	2.2	0.9
		E85 Ave.	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
Nox	ppm	Gas	4	3	4	5	4	5	4	3	3	3
		Gas Ave.	4	4	4	4	4	4	4	4	4	4
		E85	5	5	7	5	4	5	6	8	3	4
		E85 Ave.	6	6	6	6	6	6	6	6	6	6
O2	%	Gas	0.16	0.13	0.17	0.15	0.14	0.15	0.12	0.12	0.12	0.13
		Gas Ave.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
		E85	0.15	0.14	0.16	0.13	0.15	0.14	0.15	0.16	17.54	19.46
		E85 Ave.	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
AFR		Gas	11.1	14.8	14.8	14.8	14.8	14.8	14.8	14.7	14.8	14.8
		Gas Ave.	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
		E85	14.8	6.0	7.0	14.8	14.7	14.8	14.5	13.2	13.2	4.4
		E85 Ave.	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
RPM		Gas	2872	2866	2728	2923	2756	2741	2835	2652	2809	2865
		Gas Ave.	2805	2805	2805	2805	2805	2805	2805	2805	2805	2805
		E85	2859	2694	2809	2727	2851	2658	2717	2860	2871	2817
		E85 Ave.	2772	2772	2772	2772	2772	2772	2772	2772	2772	2772
Mass Calculations			Run 0	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
HC	gm/mi	Gas	0.02	0.11	0.17	0.12	0.23	0.22	0.26	0.53	0.27	0.15
		Gas Ave.	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
		E85	0.31	0.01	0.01	0.43	0.12	0.54	0.15	0.08	6.55	9.06
		E85 Ave.	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
CO	gm/mi	Gas	0.45	0.51	0.43	0.52	0.56	0.38	0.45	0.39	0.42	0.50
		Gas Ave.	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
		E85	0.19	0.45	0.30	0.13	0.21	0.18	0.22	0.31	0.09	0.34
		E85 Ave.	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
CO2	gm/mi	Gas	429	428	429	428	428	429	428	428	428	428
		Gas Ave.	428	428	428	428	428	428	428	428	428	428
		E85	533	533	533	533	533	533	533	533	530	528
		E85 Ave.	533	533	533	533	533	533	533	533	533	533
Nox	gm/mi	Gas	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		Gas Ave.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		E85	0.02	0.02	0.03	0.02	0.01	0.02	0.02	0.03	0.01	0.01
		E85 Ave.	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

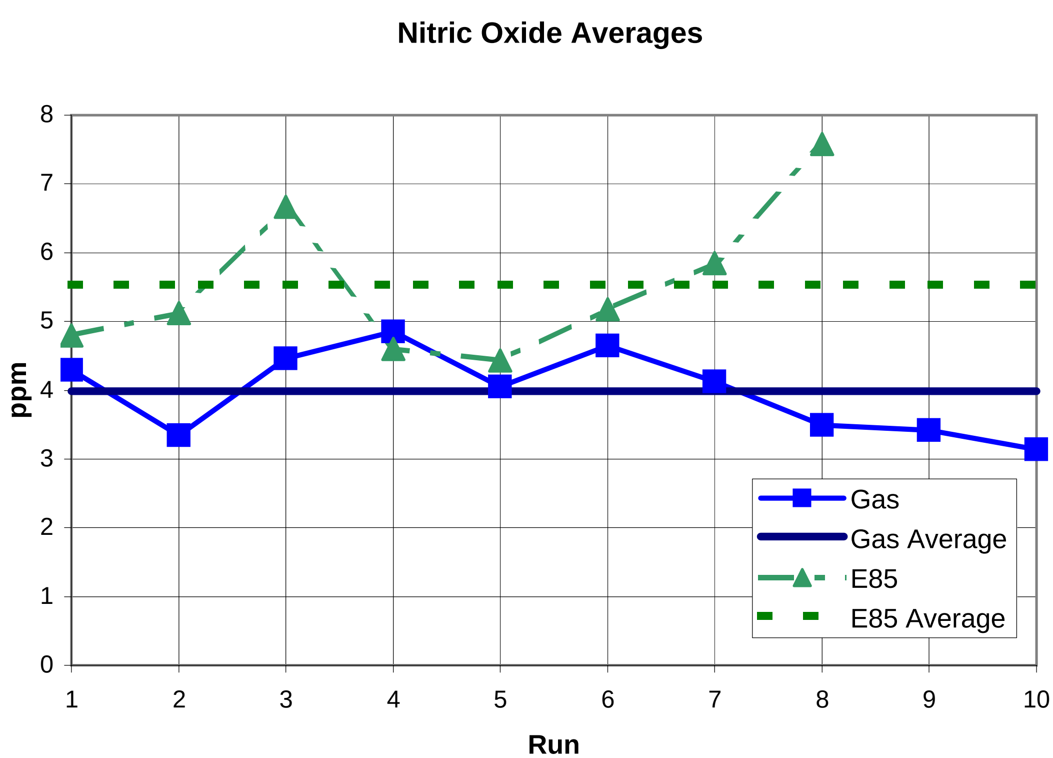
Appendix J: Emission test results - 2005 Dodge Caravan (con't)





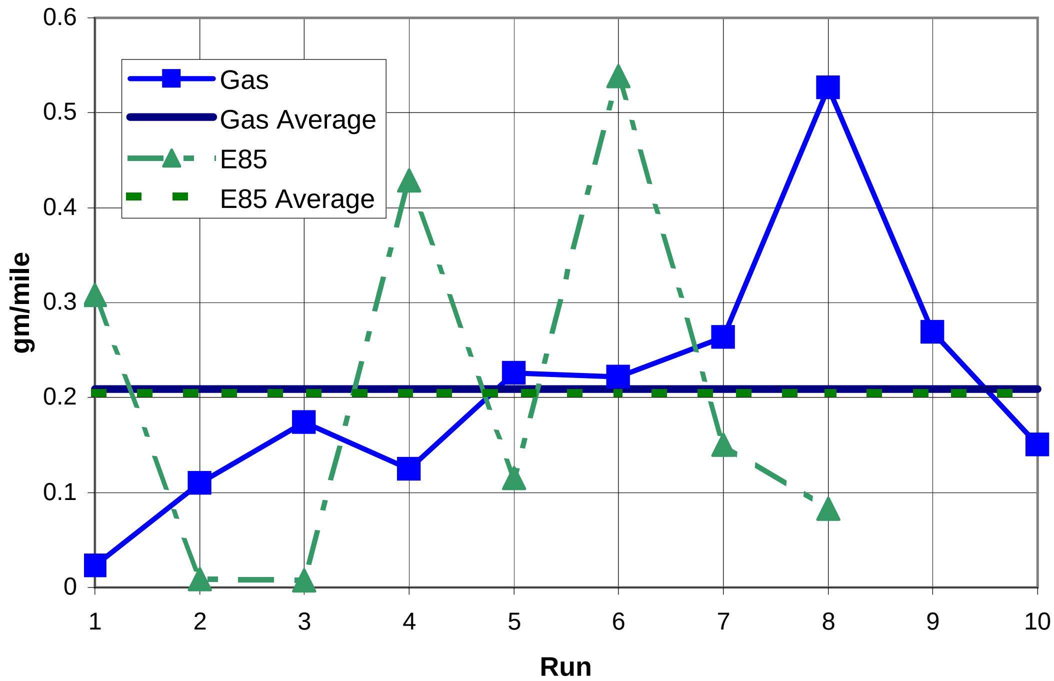
Appendix J: Emission test results - 2005 Dodge Caravan (con't)



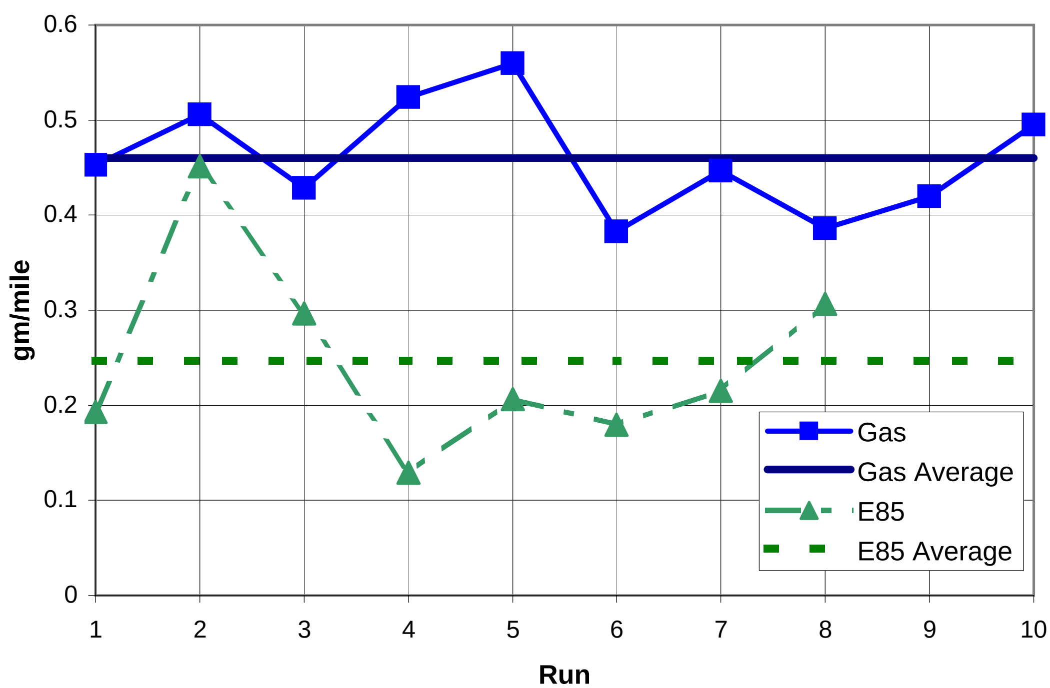


Appendix J: Emission test results - 2005 Dodge Caravan (con't)

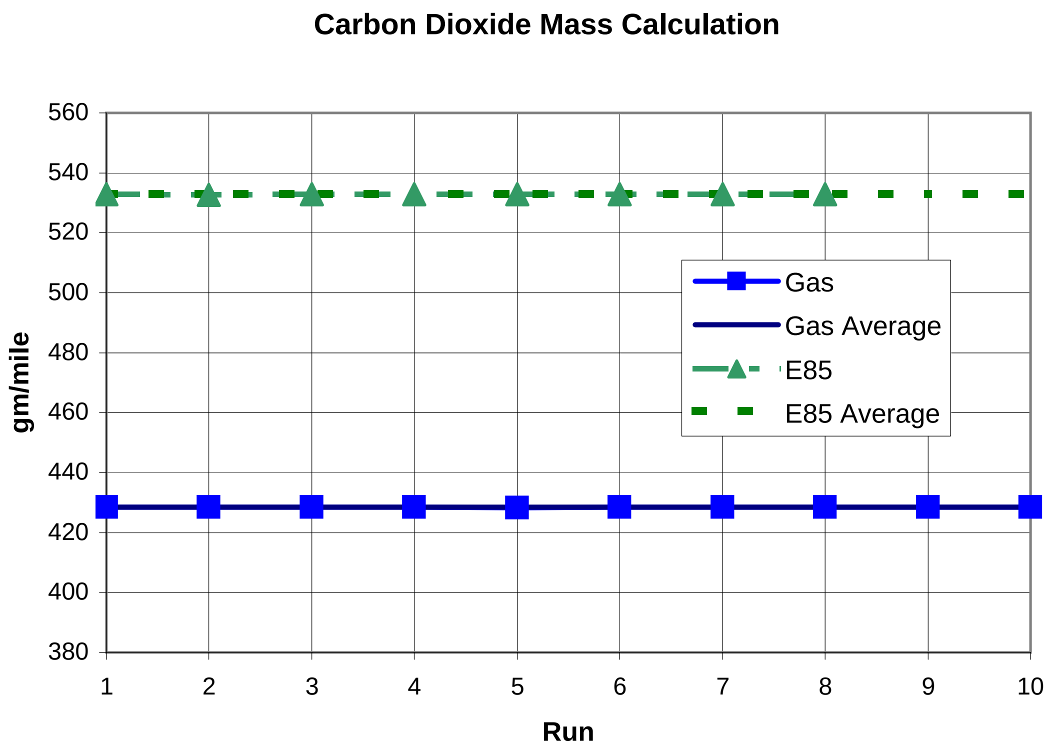
Hydrocarbon Mass Calculation

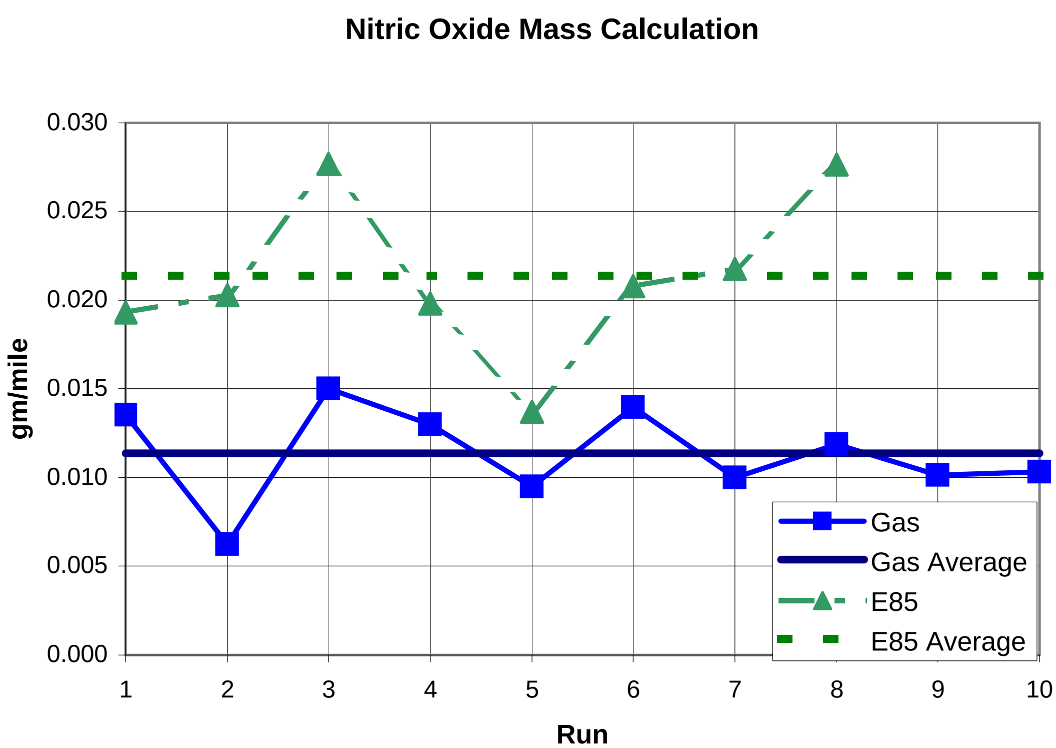


Carbon Monoxide Mass Calculation



Appendix J: Emission test results - 2005 Dodge Caravan (con't)

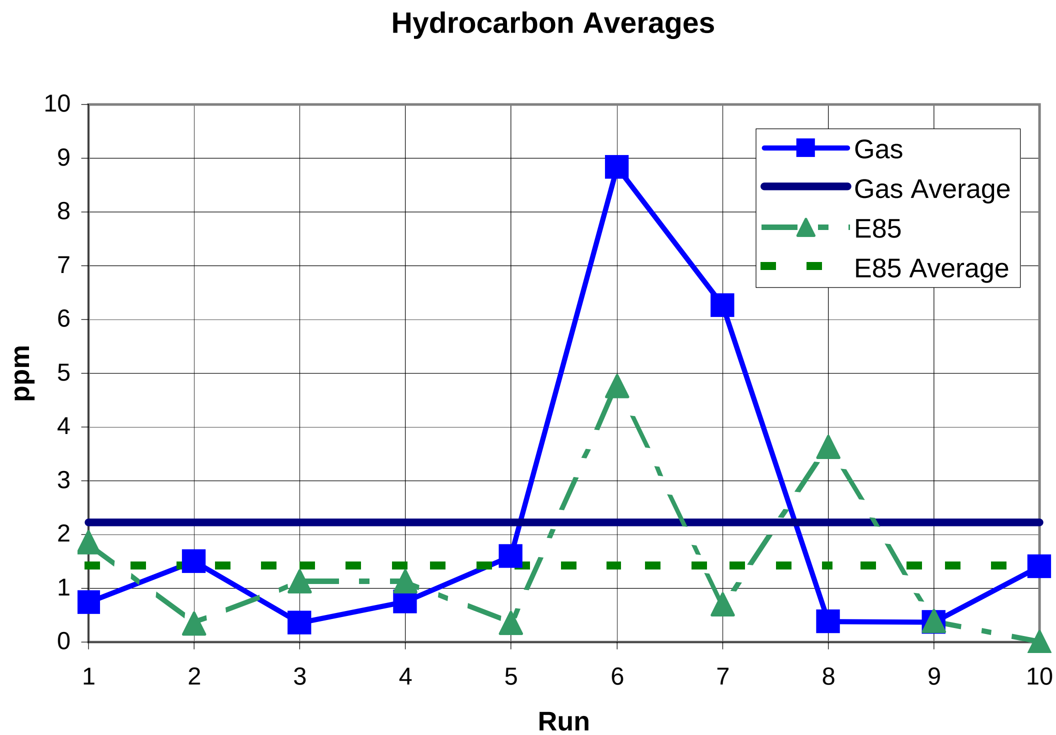


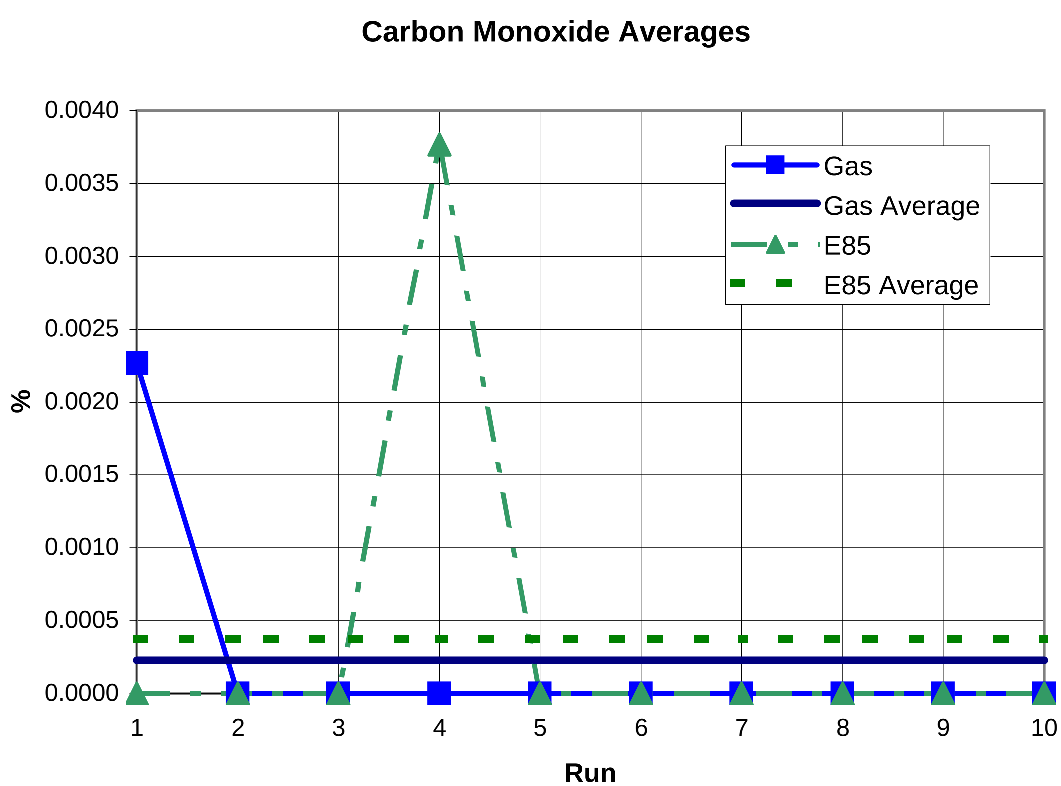


Appendix K: Emission test results - 2004 Chevy Tahoe

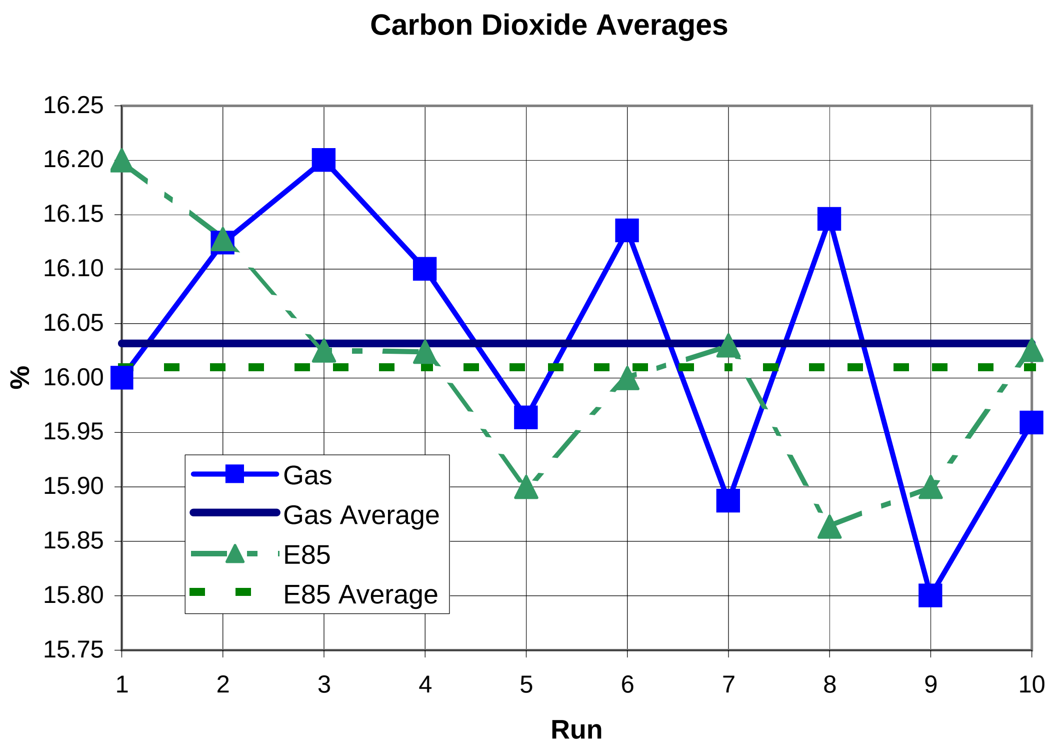
Averages			Run 0	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
HC	ppm	Gas	1	2	0	1	2	9	6	0	0	1
		Gas Ave.	2	2	2	2	2	2	2	2	2	2
		E85	2	0	1	1	0	5	1	4	0	0
		E85 Ave.	1	1	1	1	1	1	1	1	1	1
CO	%	Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Gas Ave.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		E85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		E85 Ave.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	%	Gas	16.0	16.1	16.2	16.1	16.0	16.1	15.9	16.1	15.8	16.0
		Gas Ave.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
		E85	16.2	16.1	16.0	16.0	15.9	16.0	16.0	15.9	15.9	16.0
		E85 Ave.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Nox	ppm	Gas	8	7	7	9	8	10	6	7	7	7
		Gas Ave.	8	8	8	8	8	8	8	8	8	8
		E85	4	5	5	5	5	6	5	5	5	5
		E85 Ave.	5	5	5	5	5	5	5	5	5	5
O2	%	Gas	0.11	0.19	0.09	0.10	0.10	0.10	0.18	0.19	0.12	0.10
		Gas Ave.	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
		E85	0.12	0.12	0.14	0.10	0.14	0.16	0.21	0.16	0.11	0.11
		E85 Ave.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
AFR		Gas	3.1	7.1	3.1	1.1	10.4	14.8	14.9	2.5	1.1	6.6
		Gas Ave.	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
		E85	9.1	2.3	3.4	5.4	3.4	14.7	3.3	10.2	2.4	0.9
		E85 Ave.	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
RPM		Gas	1234	1235	1218	1247	1224	1241	1227	1178	1163	1249
		Gas Ave.	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222
		E85	1219	1213	1198	1223	1212	1189	1245	1144	1178	1218
		E85 Ave.	1204	1204	1204	1204	1204	1204	1204	1204	1204	1204
Mass Calculations			Run 0	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
HC	gm/mi	Gas	0.01	0.01	0.00	0.00	0.01	0.06	0.04	0.00	0.00	0.01
		Gas Ave.	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		E85	0.02	0.00	0.01	0.01	0.00	0.05	0.00	0.03	0.00	0.00
		E85 Ave.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CO	gm/mi	Gas	0.07	0.03	0.02	0.03	0.05	0.05	0.03	0.02	0.04	0.03
		Gas Ave.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
		E85	0.04	0.02	0.01	0.09	0.03	0.01	0.04	0.03	0.03	0.03
		E85 Ave.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CO2	gm/mi	Gas	568	568	568	568	568	568	568	568	568	568
		Gas Ave.	568	568	568	568	568	568	568	568	568	568
		E85	746	746	746	746	746	746	746	746	746	746
		E85 Ave.	746	746	746	746	746	746	746	746	746	746
Nox	gm/mi	Gas	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03
		Gas Ave.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
		E85	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03
		E85 Ave.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

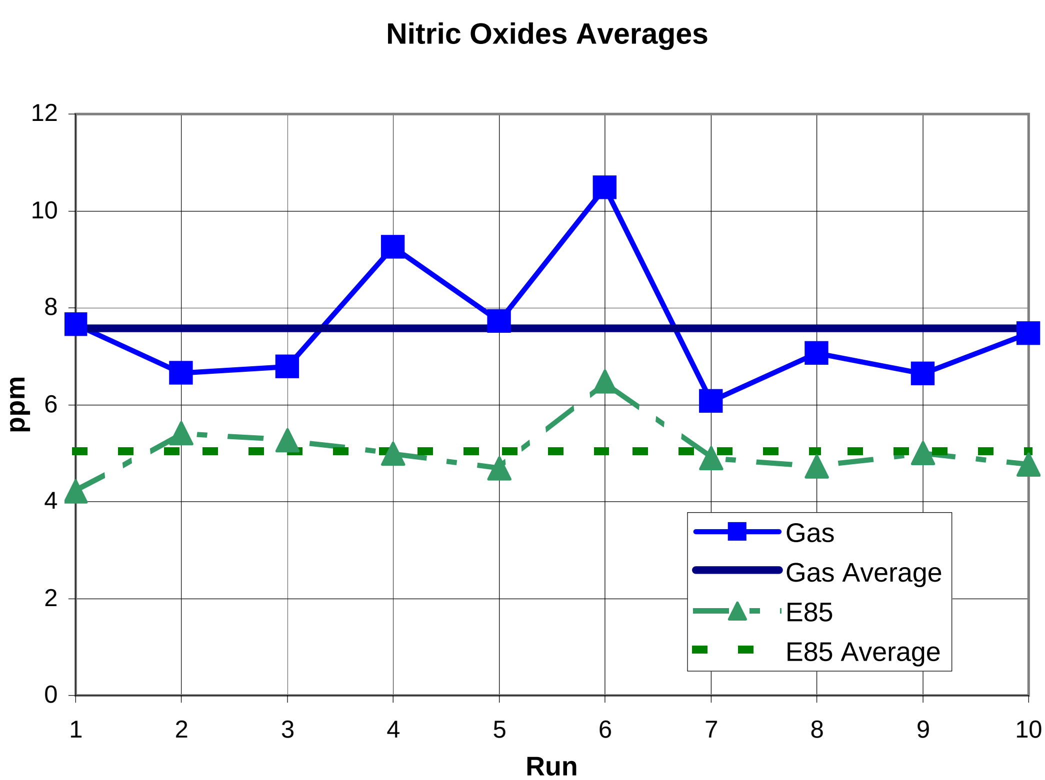
Appendix K: Emission test results - 2004 Chevy Tahoe (con't)





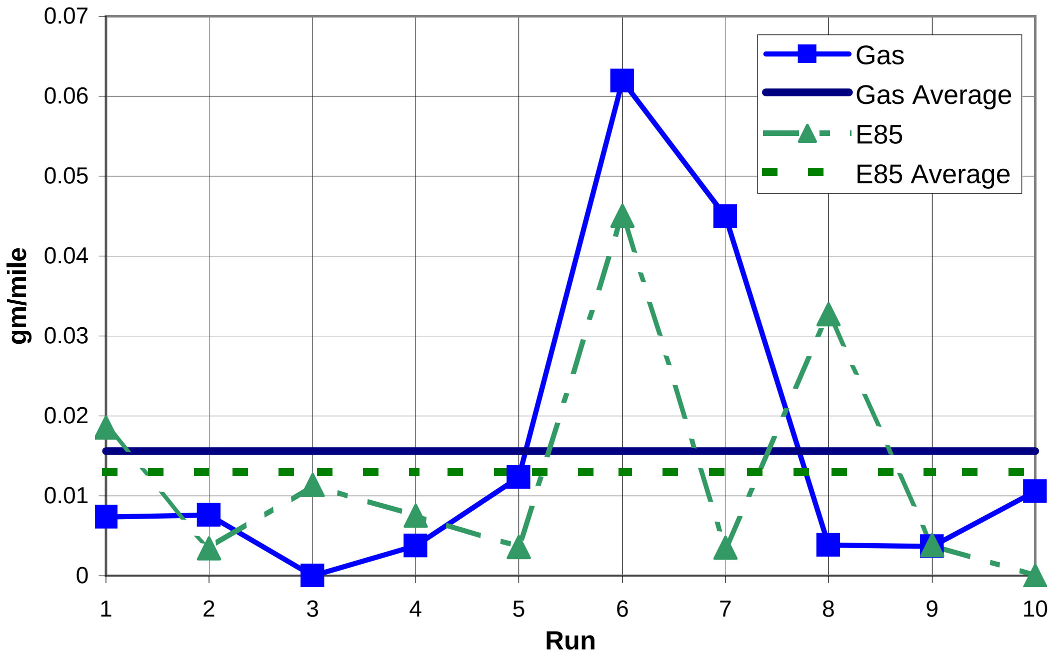
Appendix K: Emission test results - 2004 Chevy Tahoe (con't)



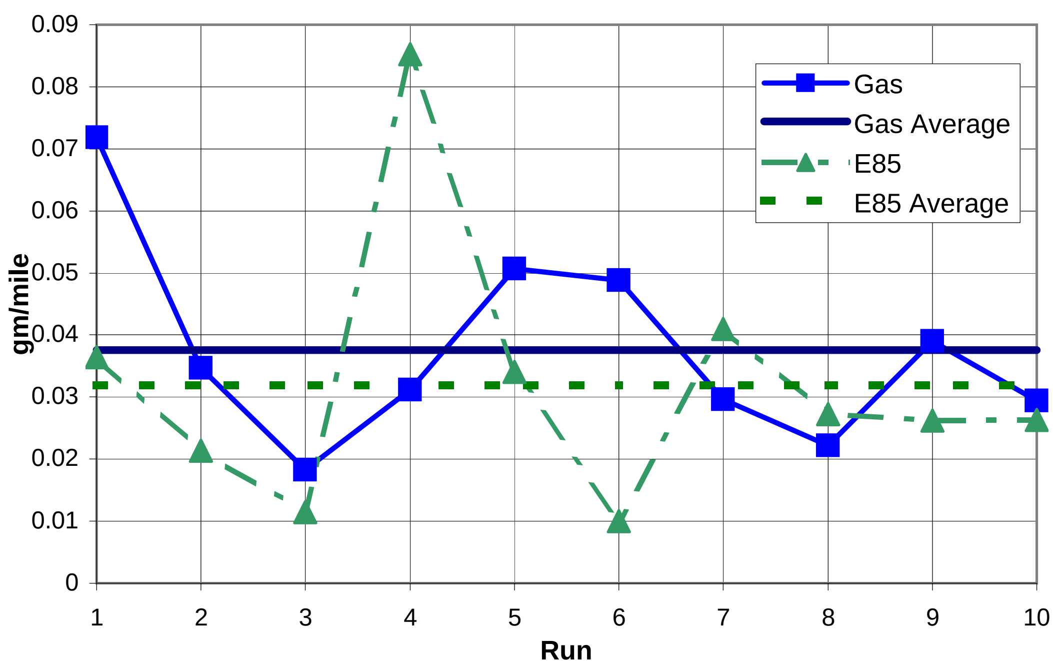


Appendix K: Emission test results - 2004 Chevy Tahoe (con't)

Hydrocarbon Mass Calculation

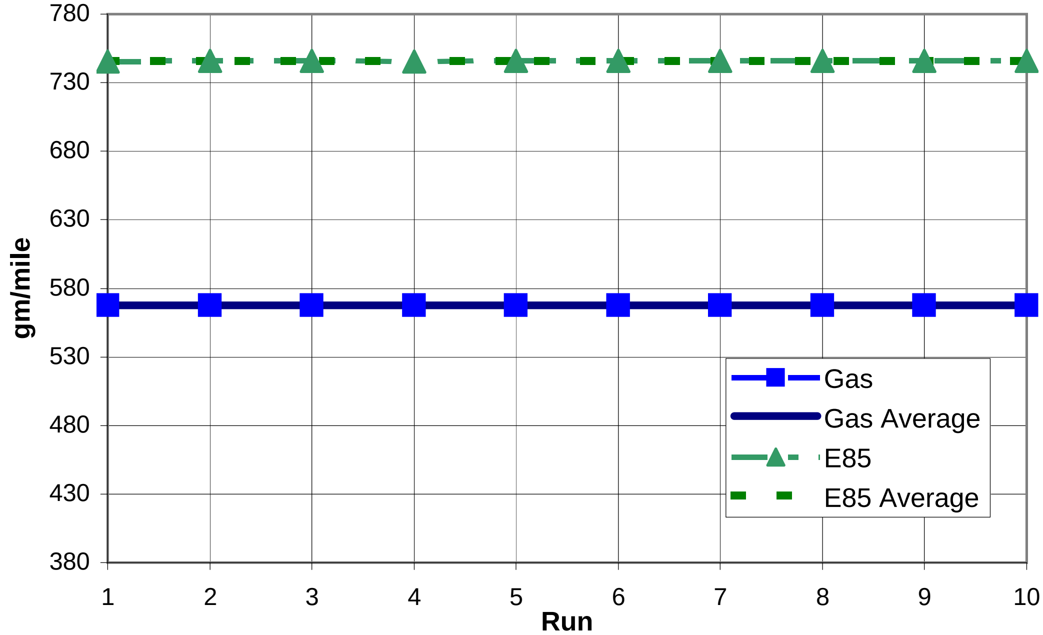


Carbon Monoxide Mass Calculation

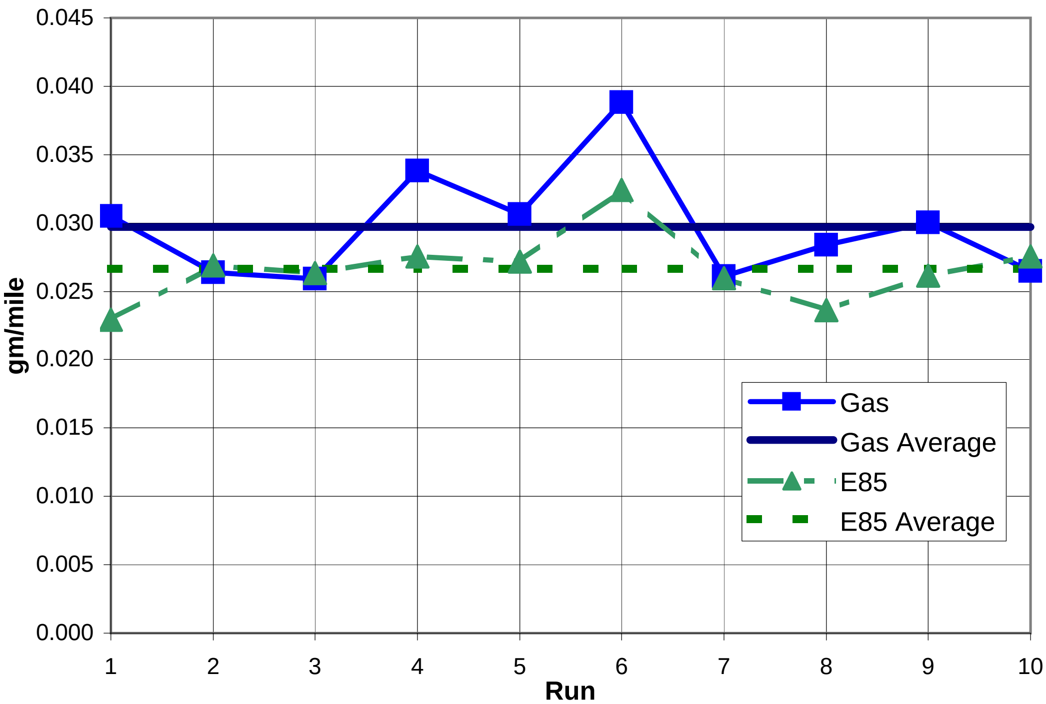


Appendix K: Emission test results - 2004 Chevy Tahoe (con't)

Carbon Dioxide Mass Calculation



Nitric Oxide Mass Calculation



Appendix L: DriveRight Carchip E/X specifications

CarChipE/X®

CarChipE/X includes all the features of CarChip, plus four times the data storage—up to 300 hours of driving data. (The actual number of hours will vary, depending on how frequently you log data.)

As with CarChip, you'll get time and date for each trip, distance, speed, hard accelerations and decelerations, and engine diagnostic trouble codes.

With CarChipE/X, though, you'll also be able to monitor any four out of 23 user-selectable engine parameters, including:

RPM	Throttle position	Engine Load
Fuel pressure	Fuel system status	Short- and long-term-fuel trim
Battery voltage	Timing advance	Coolant temperature
Air flow rate	Intake air temperature	intake manifold pressure

Plus, if you're unfortunate enough to be involved in an accident, CarChipE/X will automatically generate an accident log showing the last critical 20 seconds of speed.

Includes data logger, software on CD, and USB cable for downloading data. Requires Windows 98SE/2000/ME/XP and one USB port.

Buy it now, using our secure e-commerce system. Or click "More Info" to download copies of our catalog pages, specifications, or instruction manuals.

Vehicle Conflicts and Exclusions

There are a few vehicles in which CarChip does not function properly, and there are others in which CarChip may interfere with the normal operation of the vehicle. Please review the list of known CarChip Vehicle Conflicts and Exclusions before purchasing or using CarChip.

Important Safety Notice

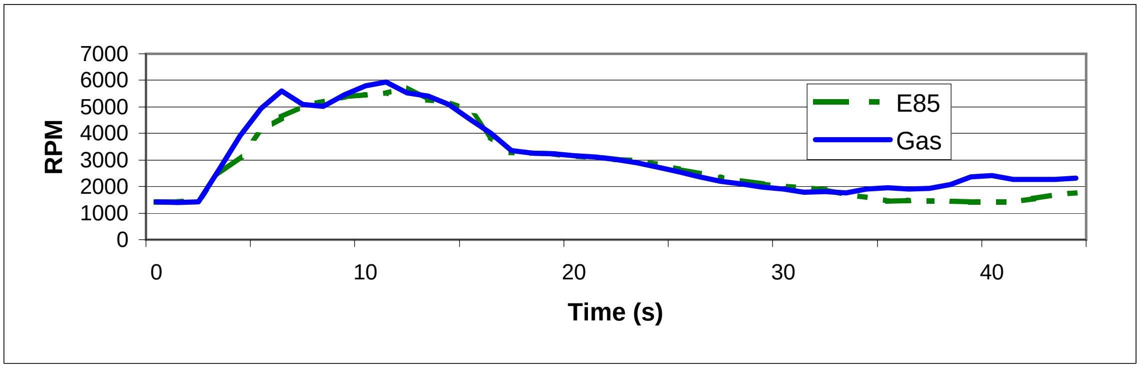
CarChip has been carefully designed and tested to comply with the OBDII protocols used on most cars and light trucks sold in the USA, model-year 1996 or later. However, some vehicle models are not in full compliance with these protocols. In addition, the computer control systems on any given vehicle may be malfunctioning or out of spec, as may be the sensors used by these systems.

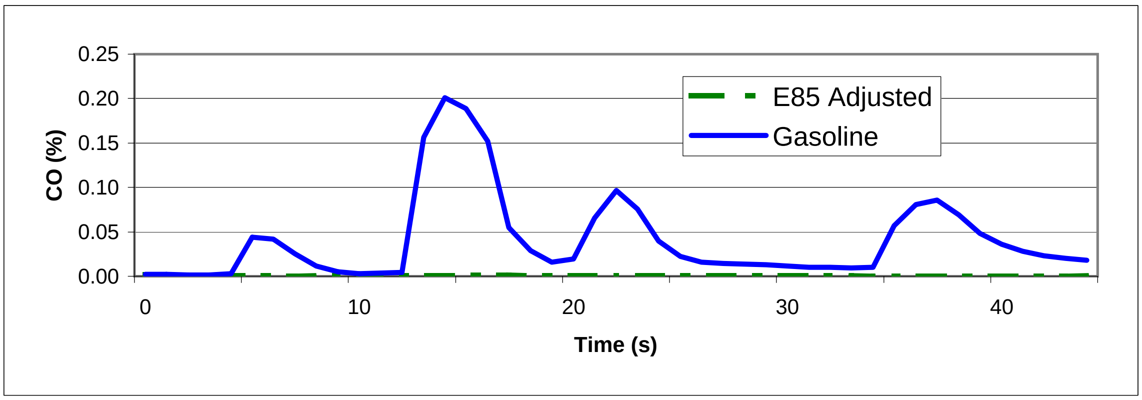
Before installing CarChip, be sure to review the list of known vehicle exclusions and anomalies (see the link above). For more information on OBDII issues and anomalies in general, we recommend The Equipment and Tool Institute's website at www.etools.org.

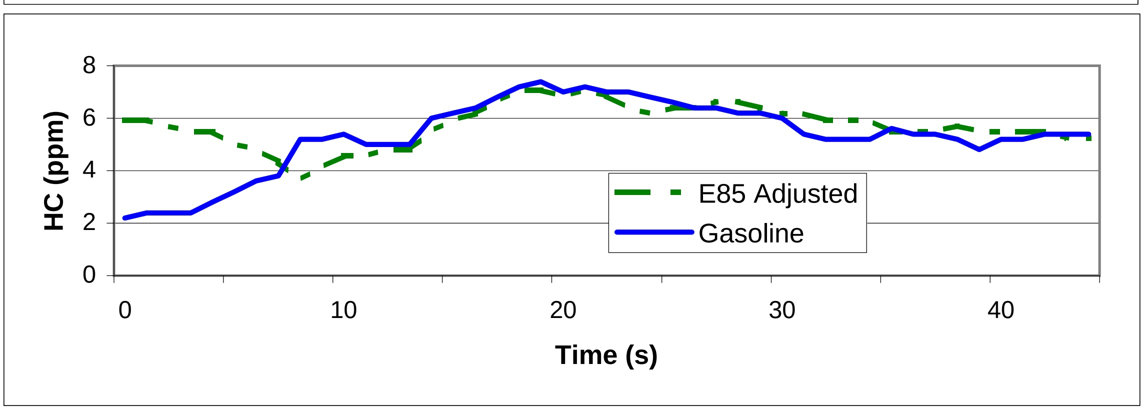
While our testing and the experience of thousands of CarChip users have shown the unit to be safe and reliable, there is an inherent risk in adding any aftermarket product that may potentially affect the operation or drivability of your vehicle. **Should you be concerned about the operation of your vehicle at any time while using CarChip, you should pull over, off the roadway, immediately or as soon as it is safe to do so. Remove CarChip from the OBDII port and consult a licensed mechanic or automobile service center.**

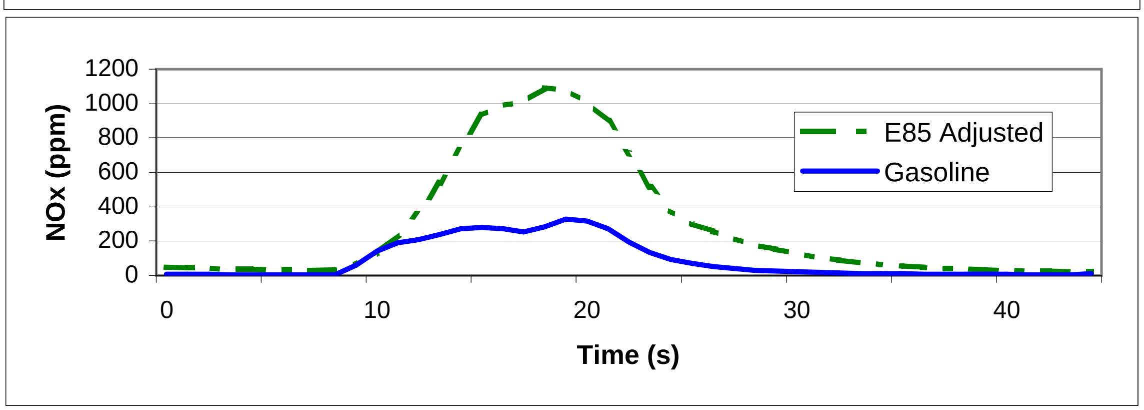
Appendix M; Individual emissions event

Taurus: Hard Acceleration at Varsity/Western and stop at Western/Gorman



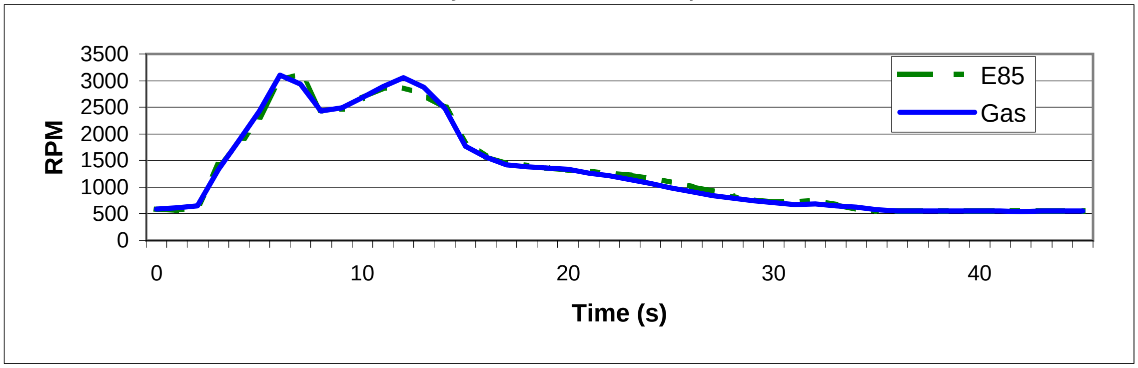


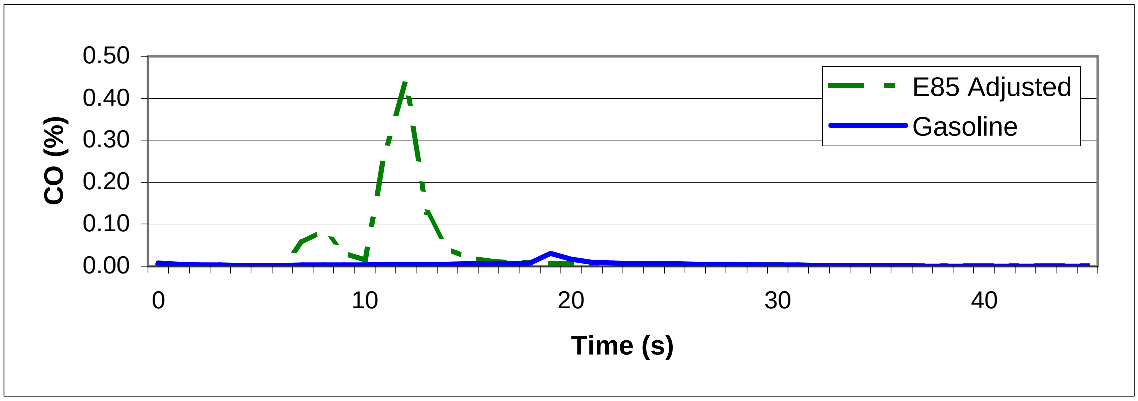


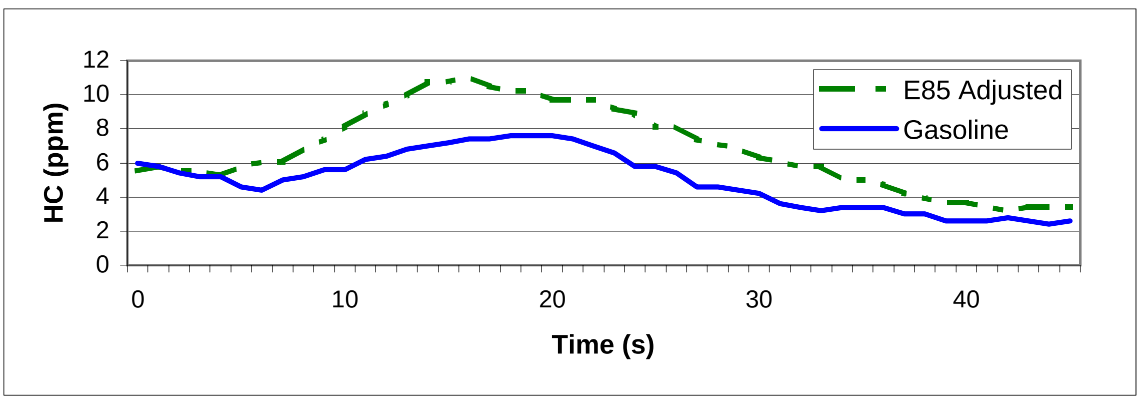


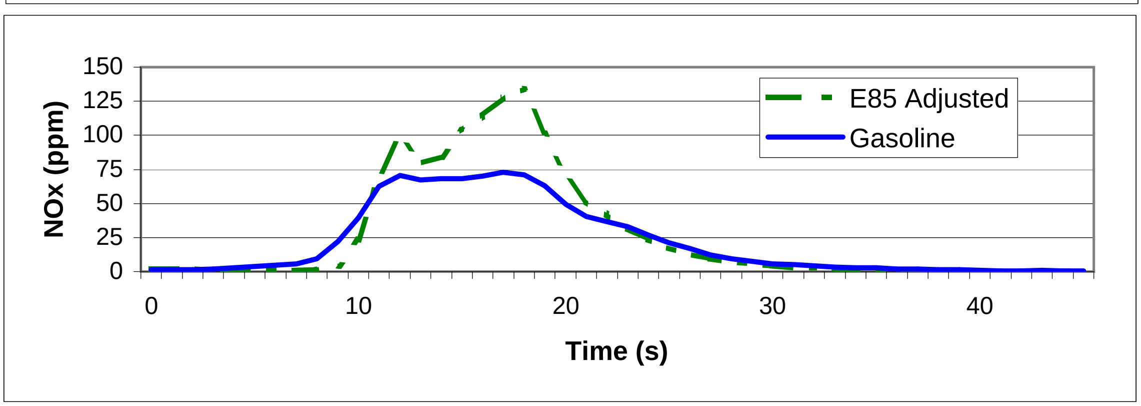
Appendix M; Individual emissions event

Tahoe: Hard Acceleration at Varsity/Western and stop at Western/Gorman



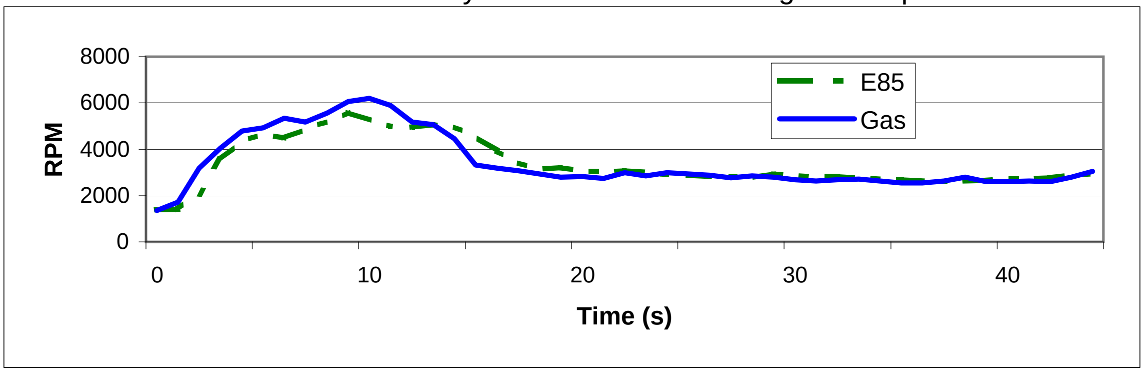


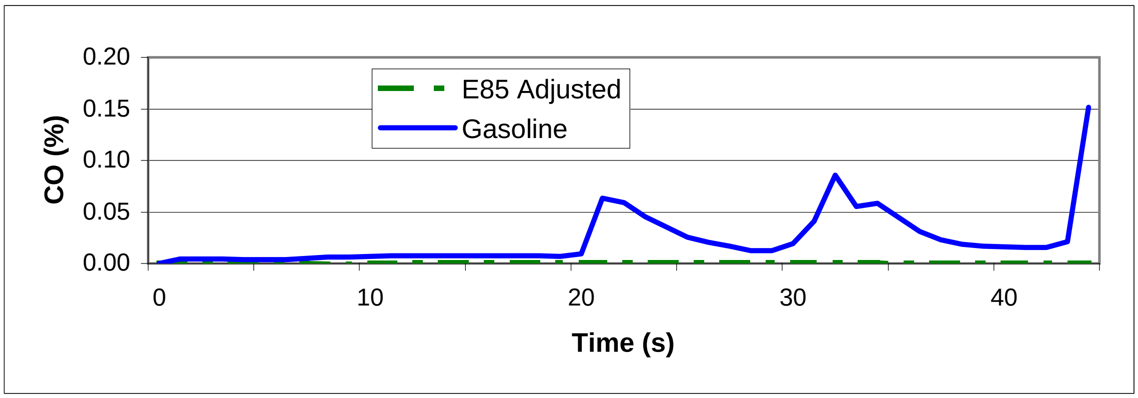


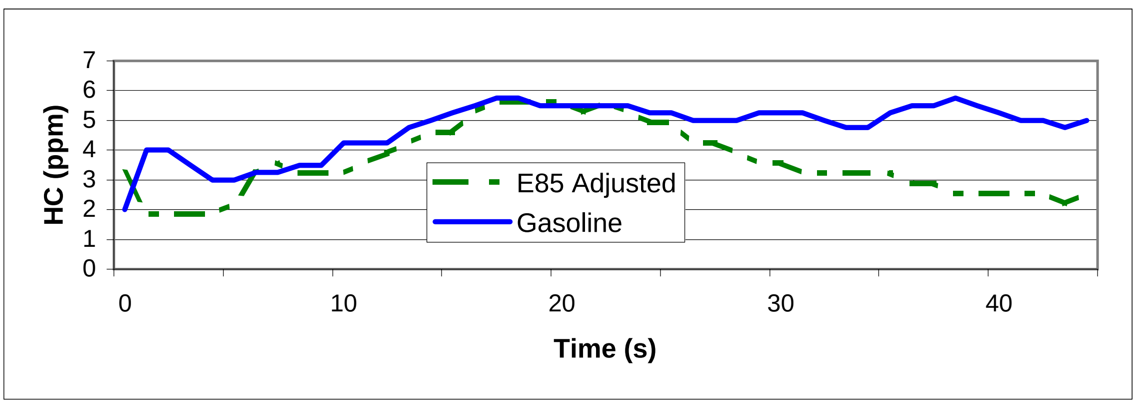


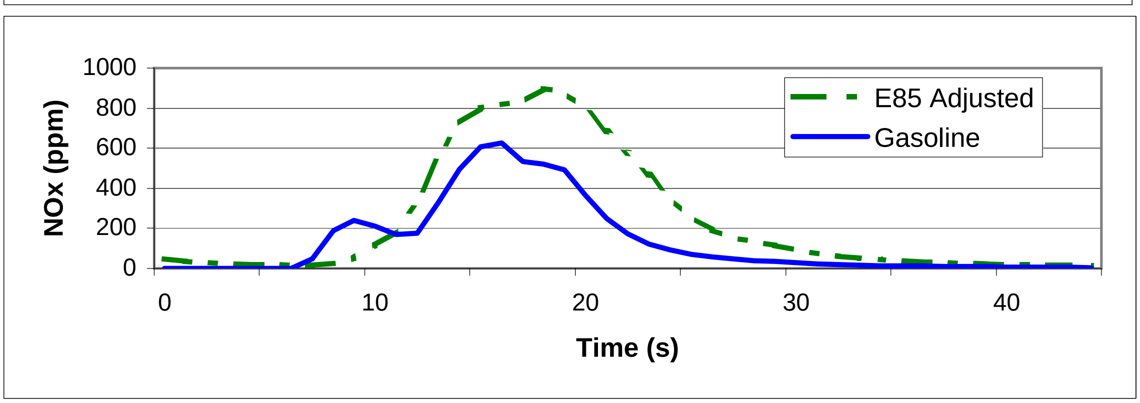
Appendix M; Individual emissions event

Taurus: Hard Acceleration at Varsity/Western and continuing at 45 mph



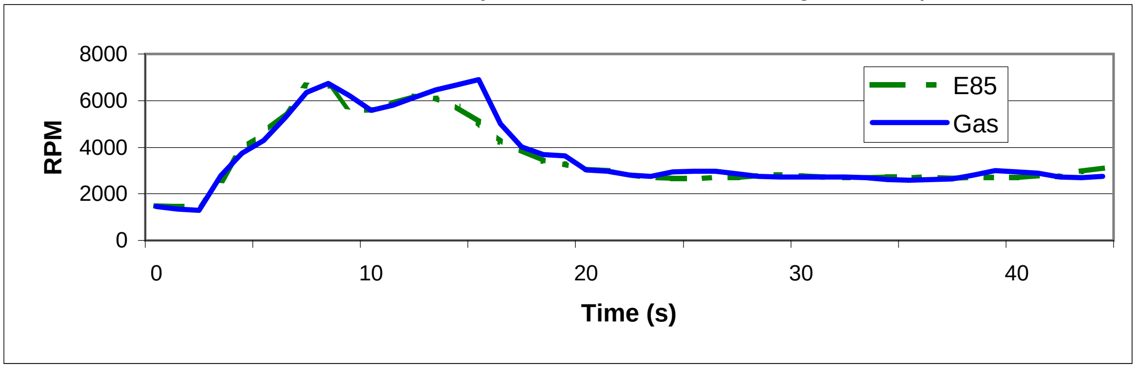


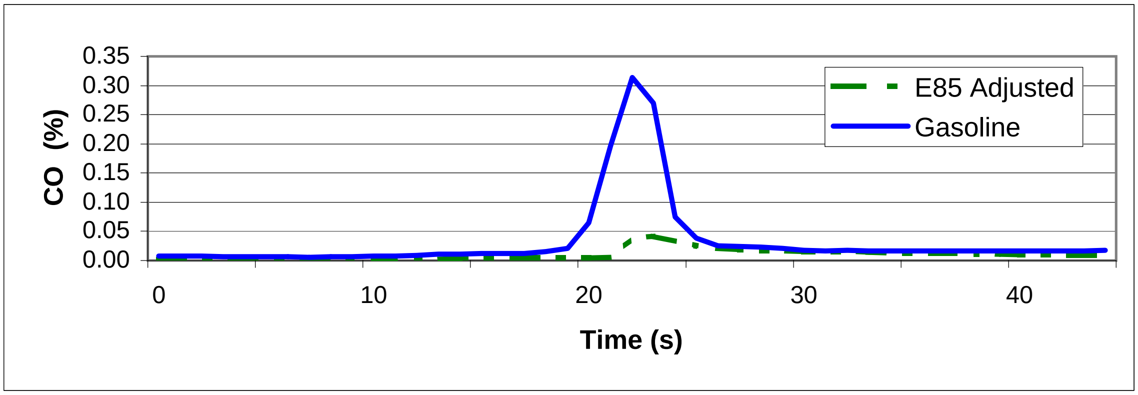


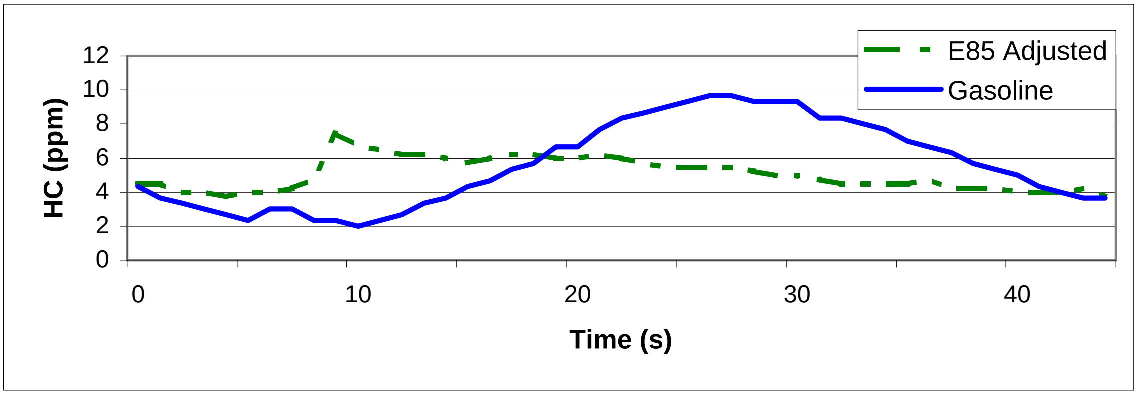


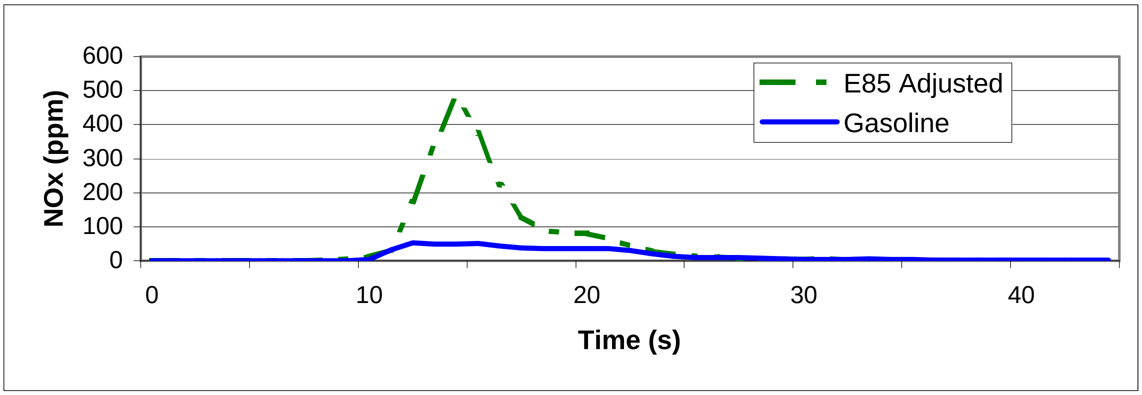
Appendix M; Individual emissions event

Caravan: Hard Acceleration at Varsity/Western and continuing at 45 mph



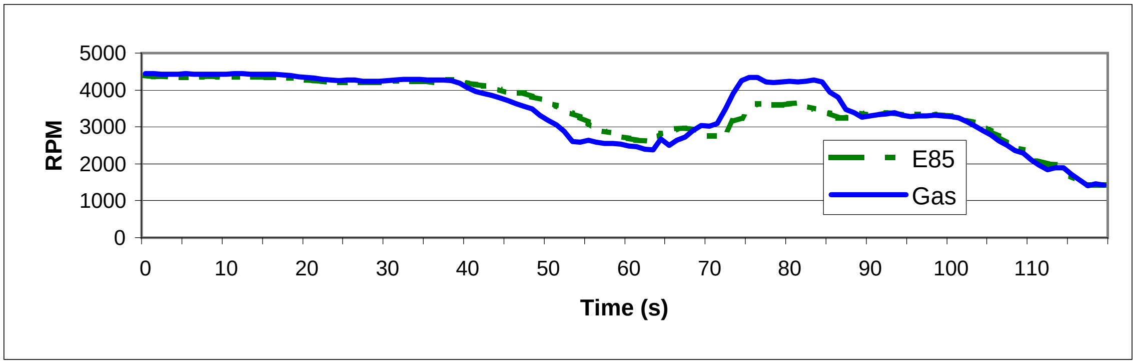


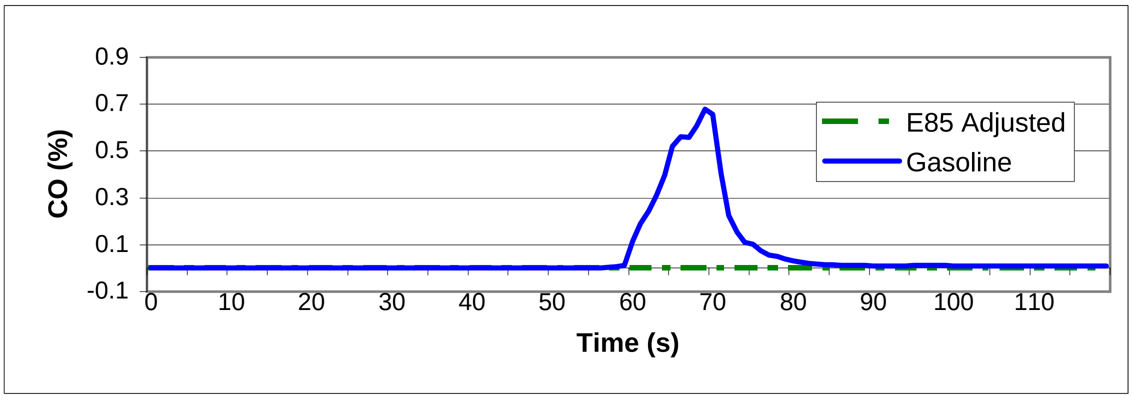


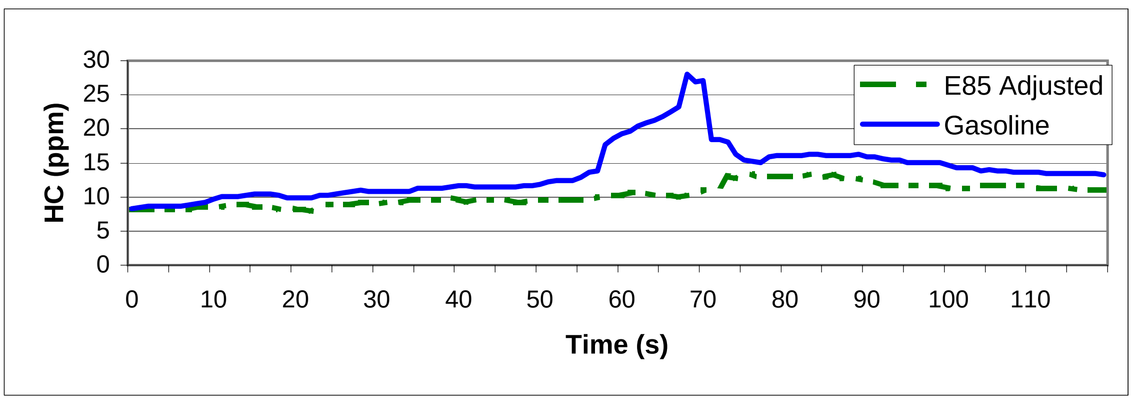


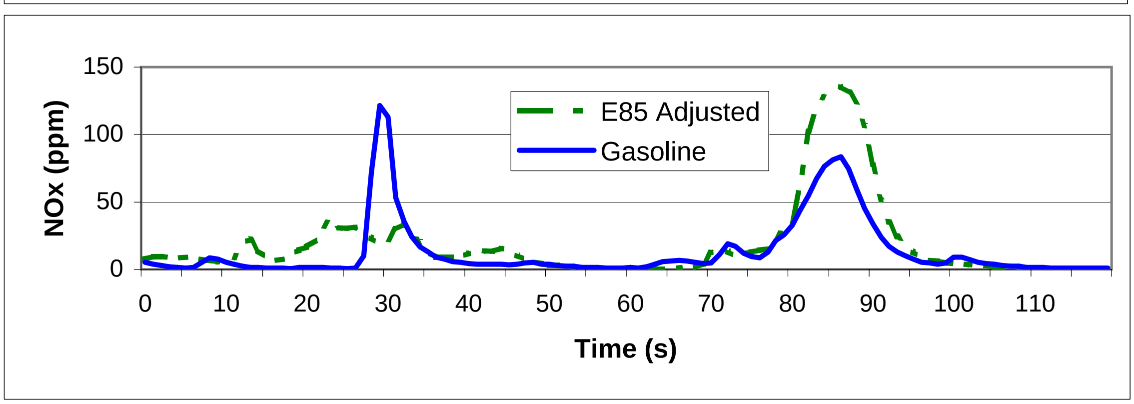
Appendix M; Individual emissions event

Taurus: Exit from 440, accelerate after ramp to stop at Glenwood/Pasquotank



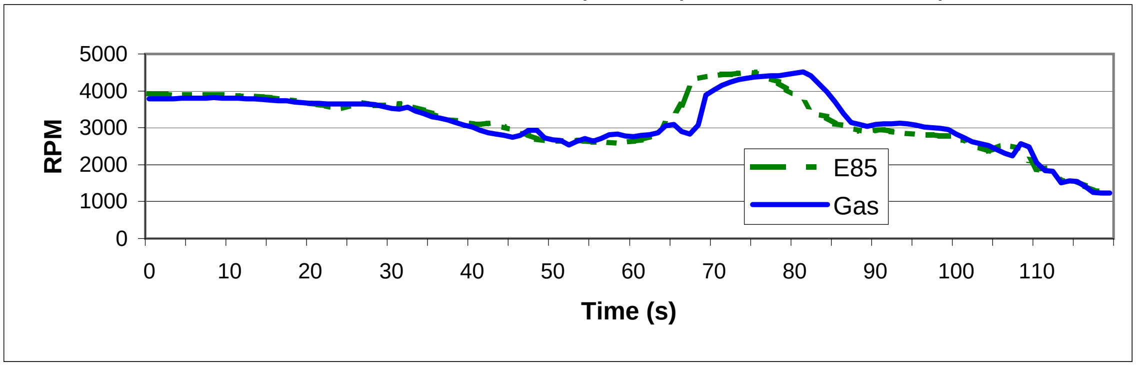


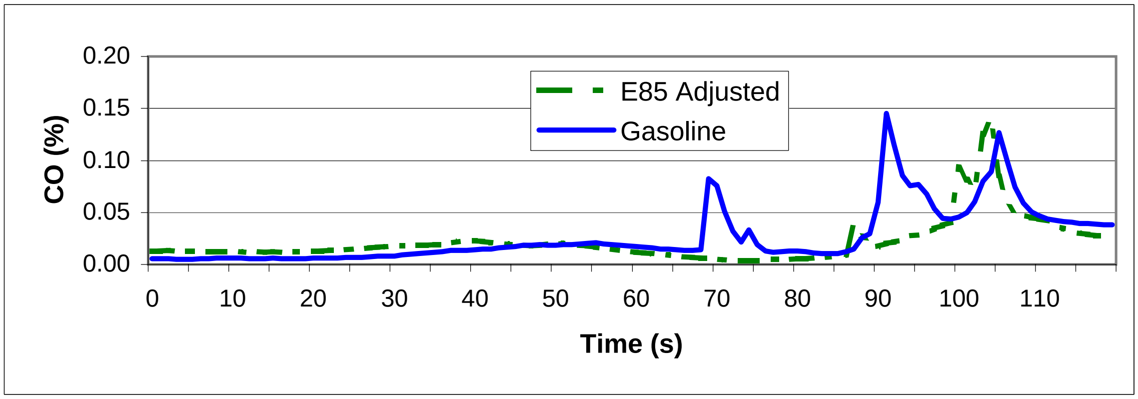


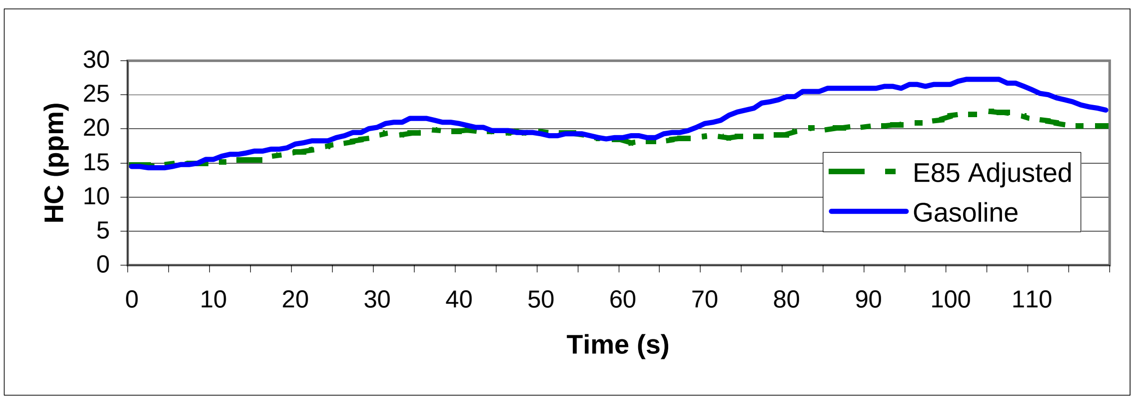


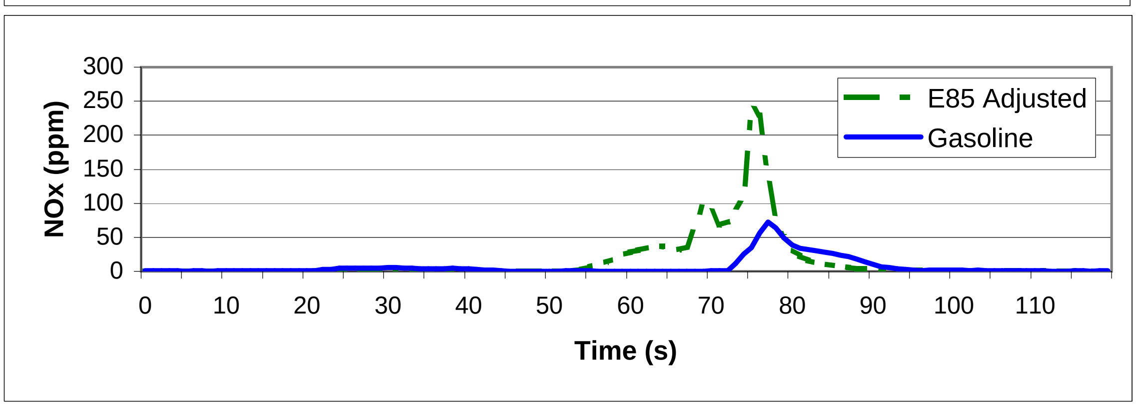
Appendix M; Individual emissions event

Caravan: Exit from 440, accelerate after ramp to stop at Glenwood/Pasquotank



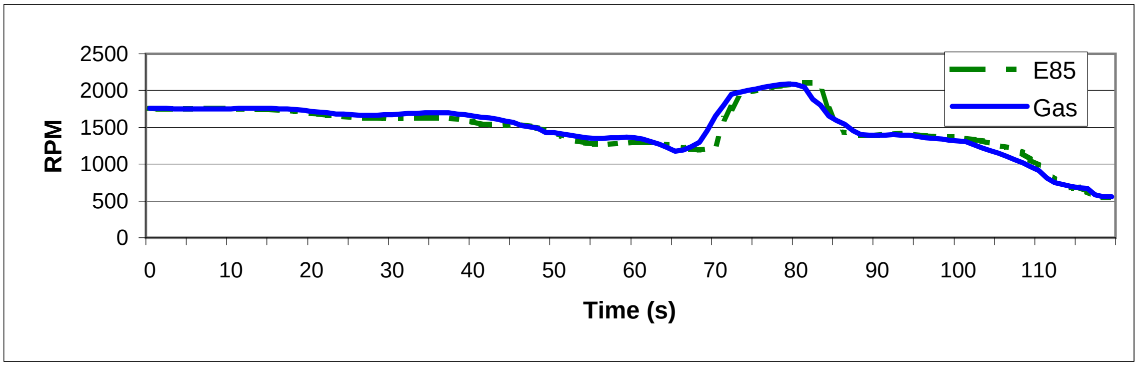


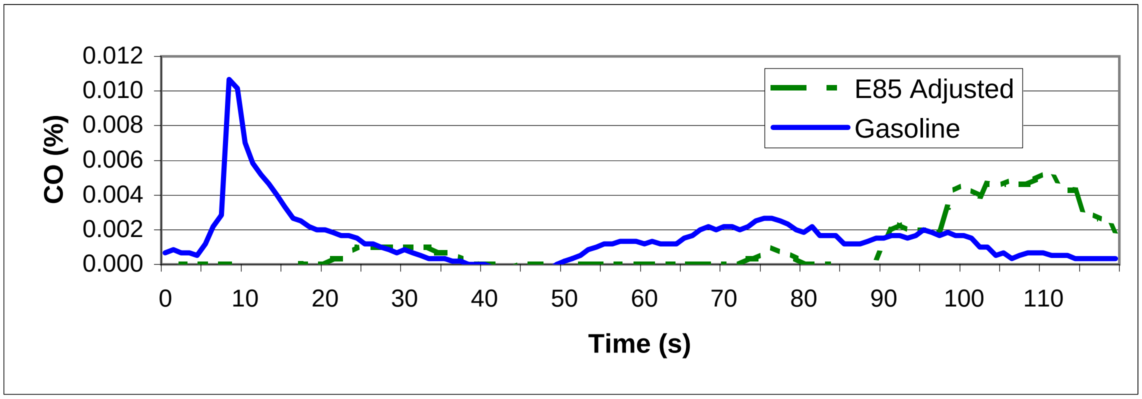


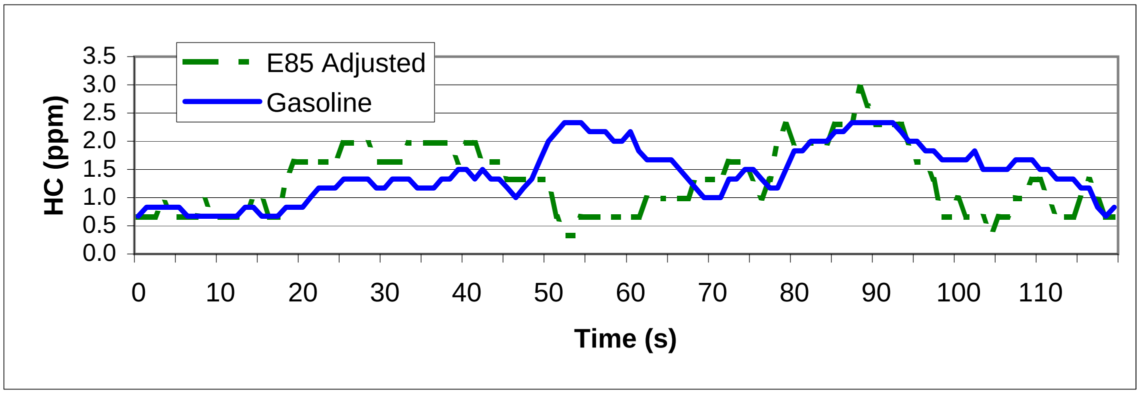


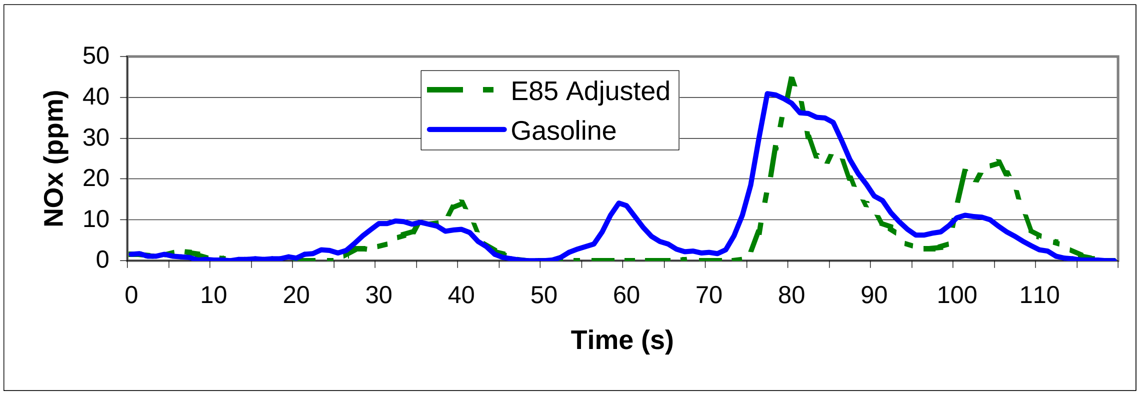
Appendix M; Individual emissions event

Tahoe: Exit from 440, accelerate after ramp to stop at Glenwood/Pasquotank



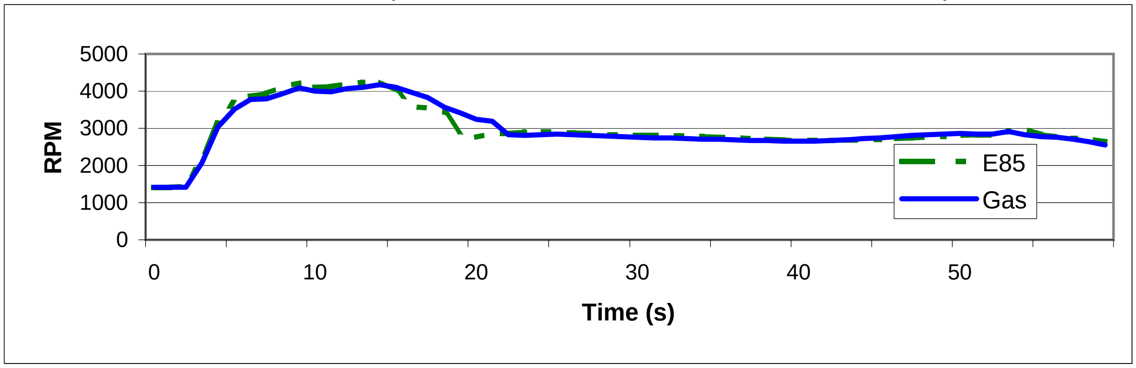


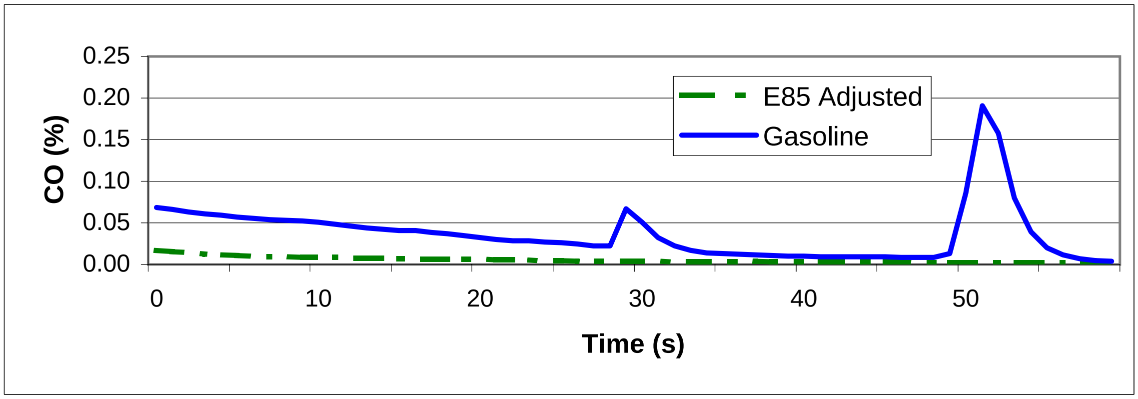


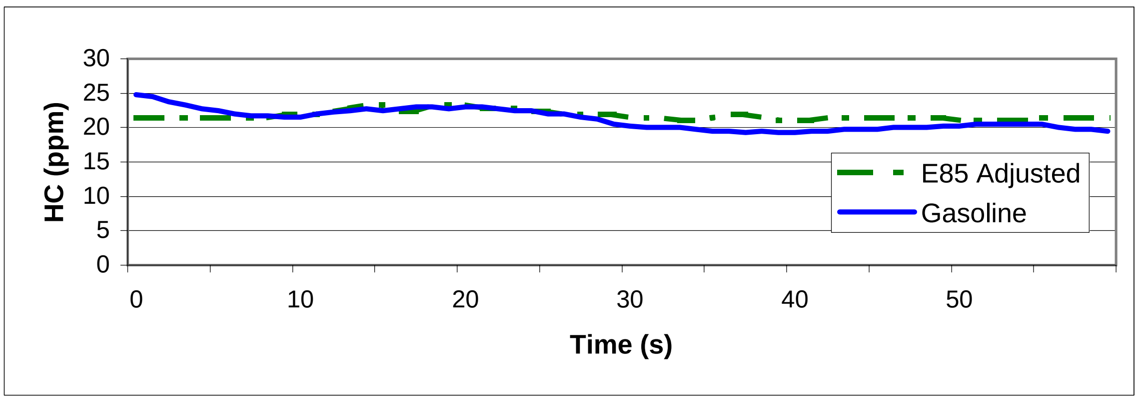


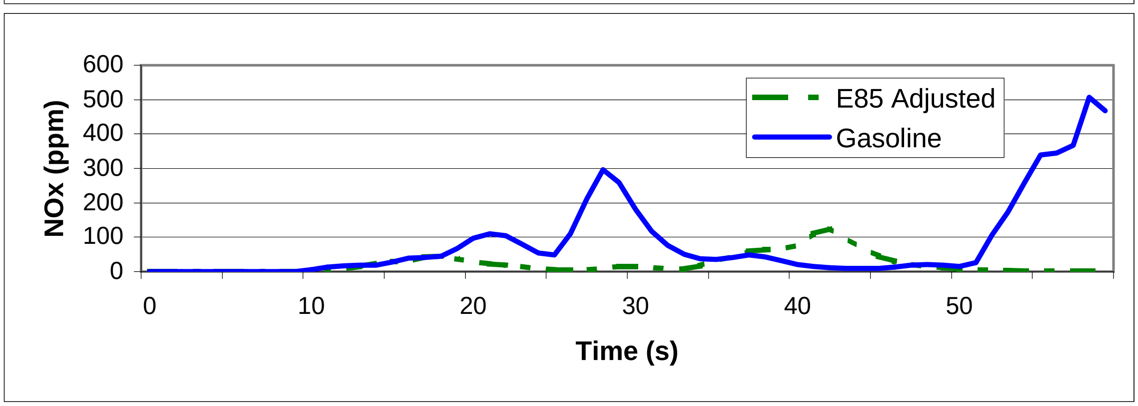
Appendix M; Individual emissions event

Taurus: Acceleration from Stop at Glenwood/Oberlin to continue at 45 mph



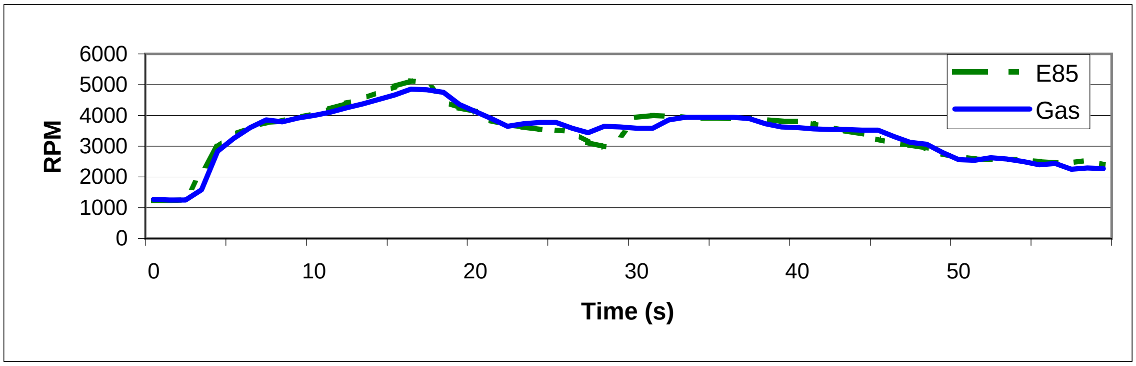


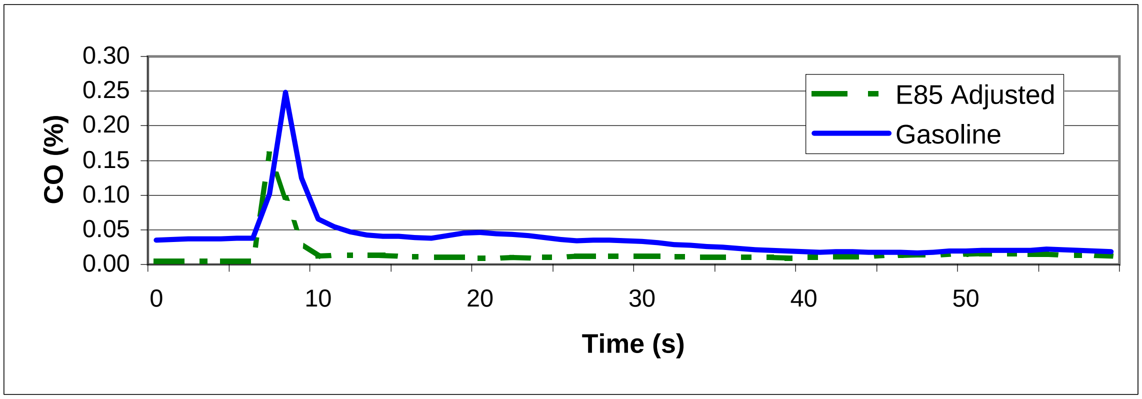


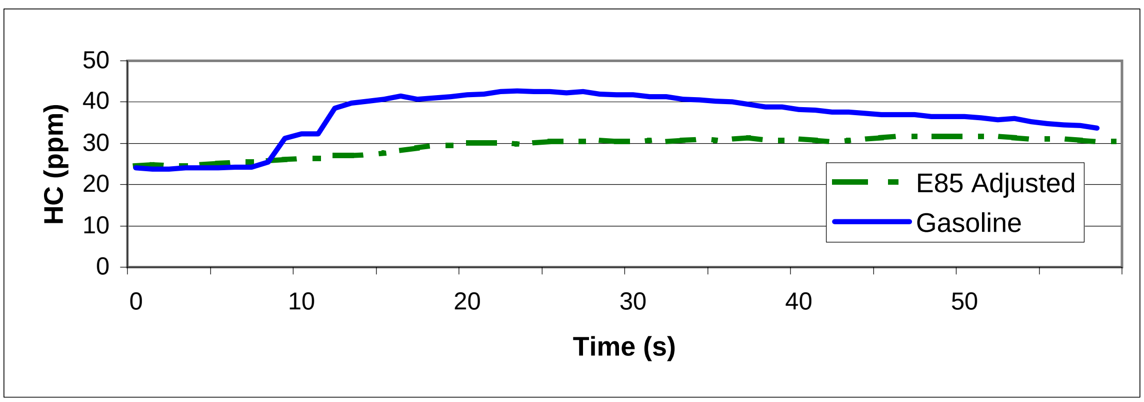


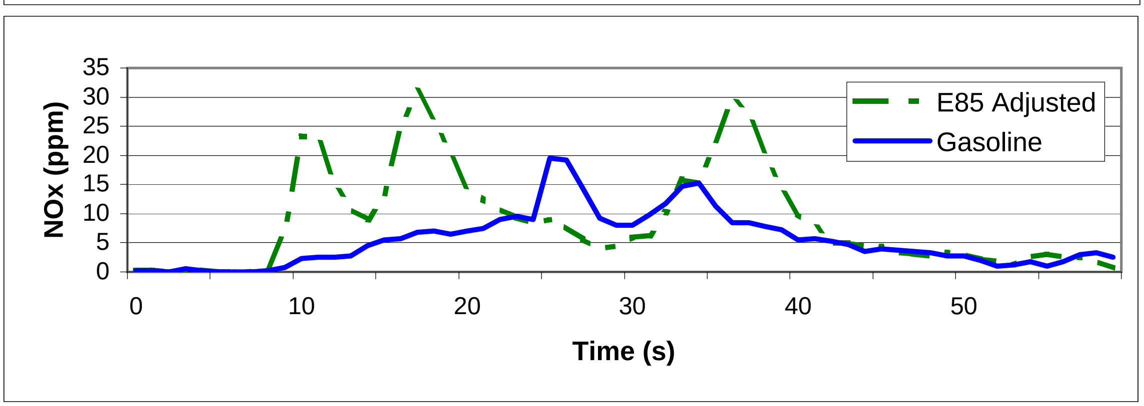
Appendix M; Individual emissions event

Caravan: Acceleration from Stop at Glenwood/Oberlin to continue at 45 mph



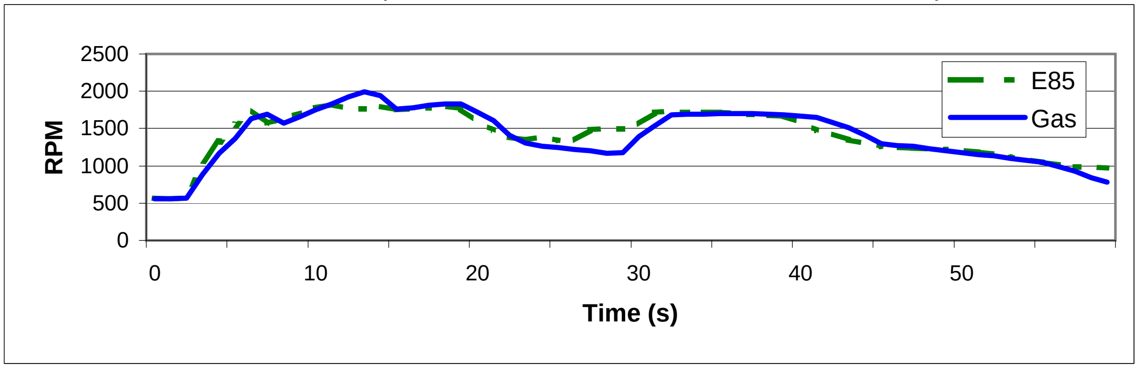


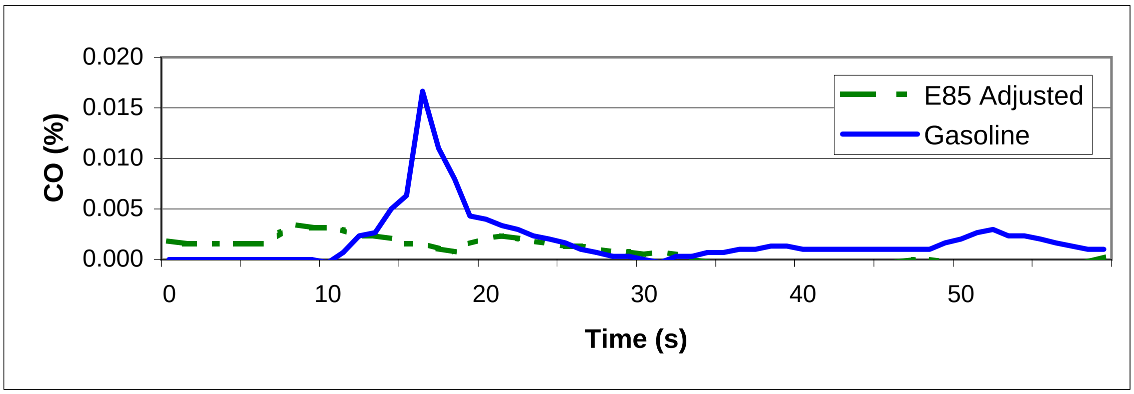


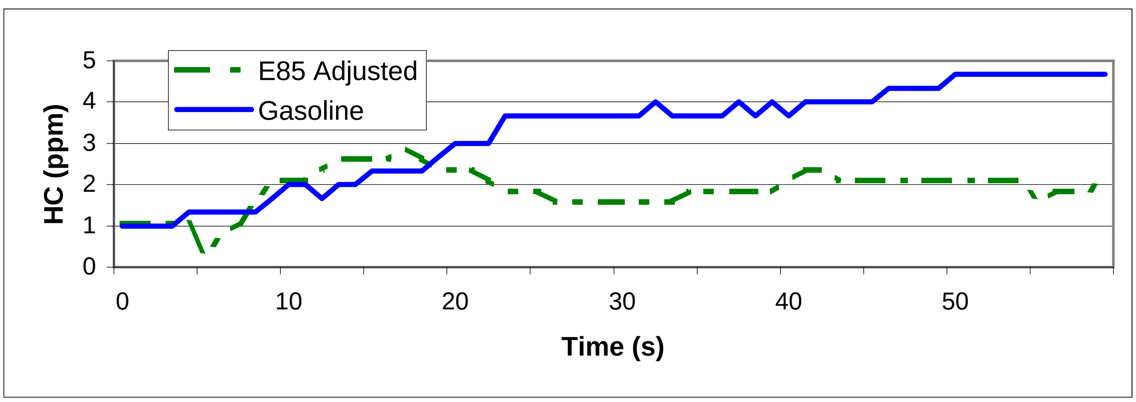


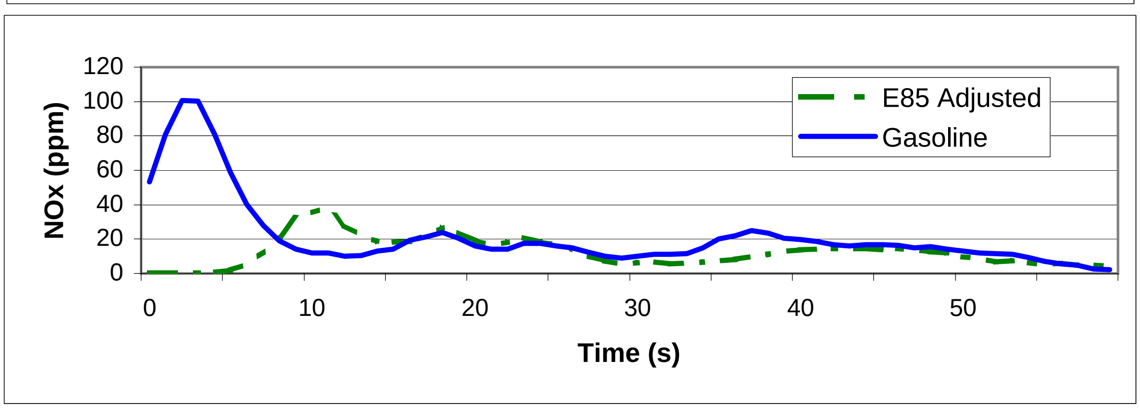
Appendix M; Individual emissions event

Tahoe: Acceleration from Stop at Glenwood/Oberlin to continue at 45 mph



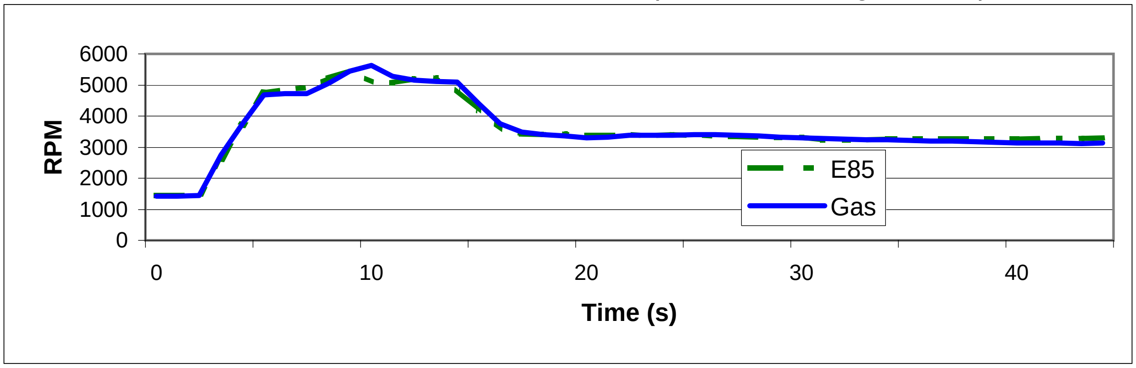


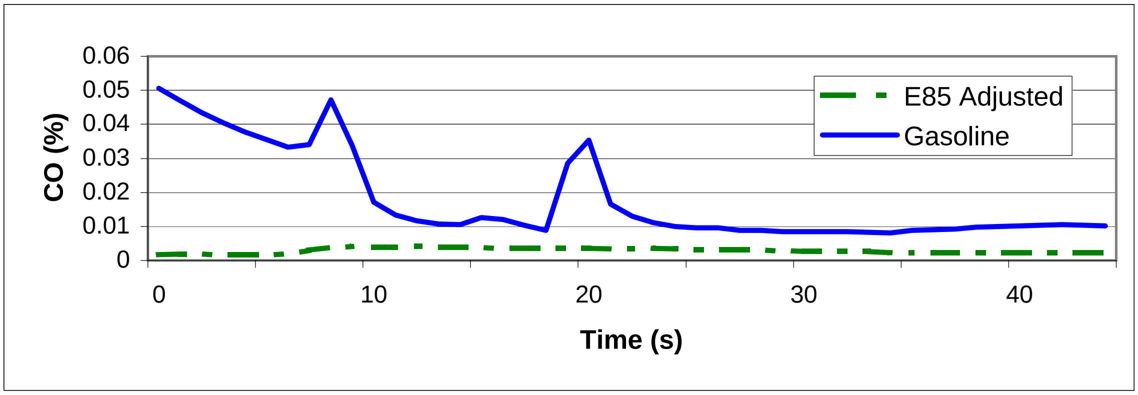


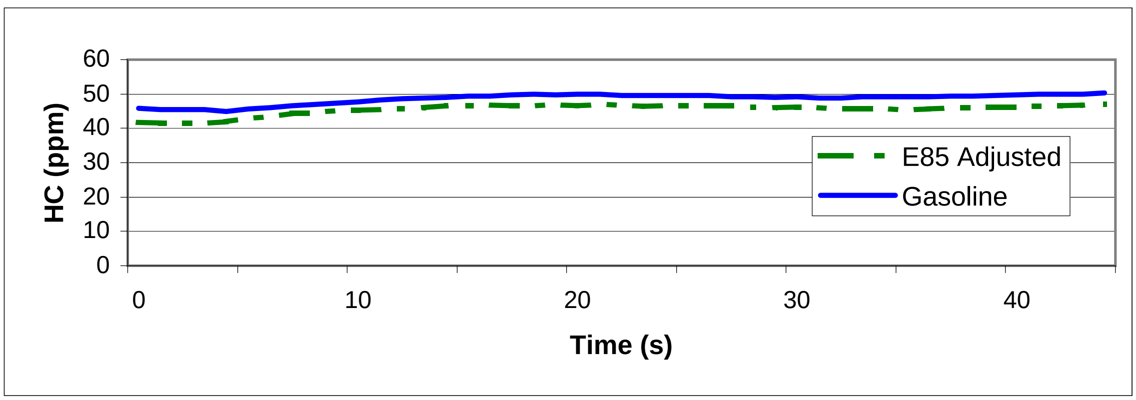


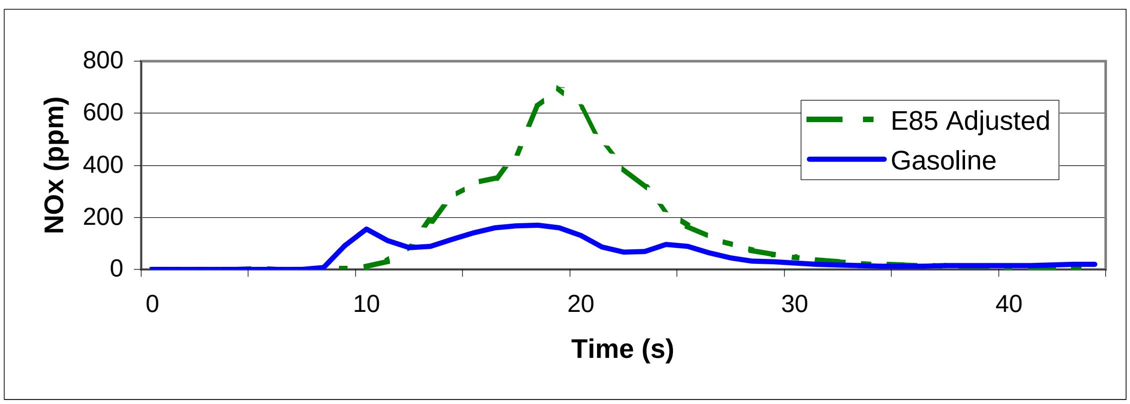
Appendix M; Individual emissions event

Taurus: Hard Acceleration from Ashe/Western stop and continuing at 45 mph



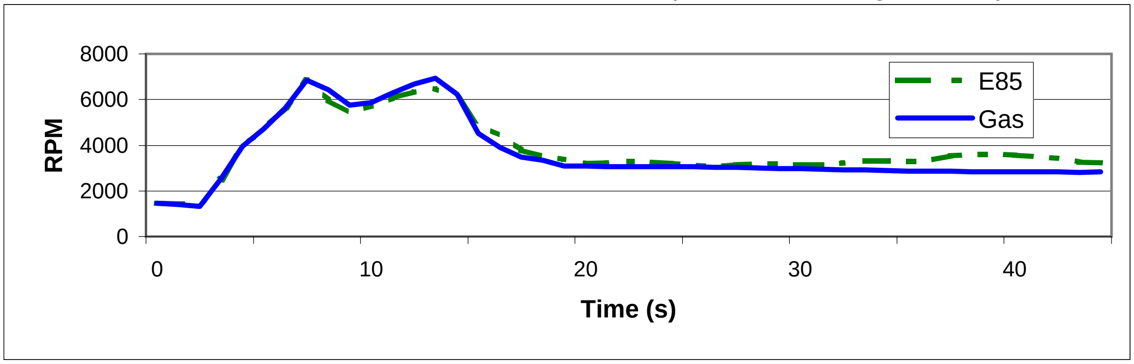


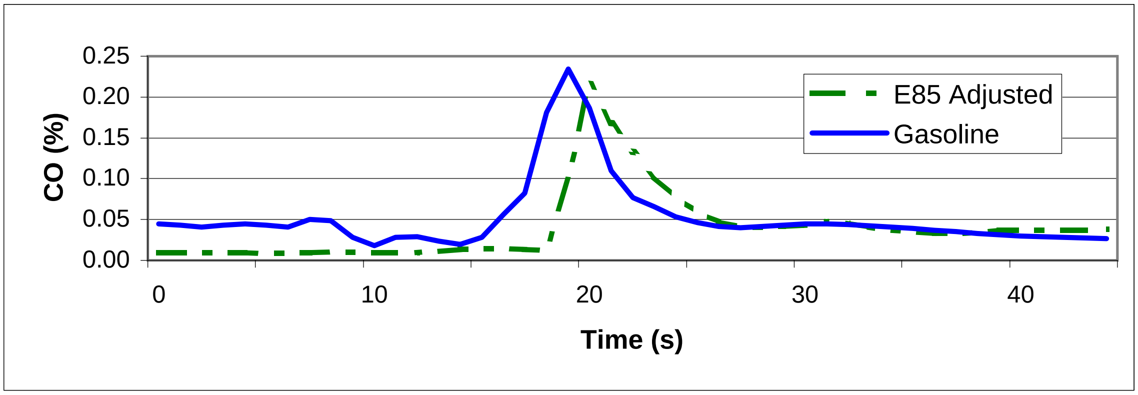


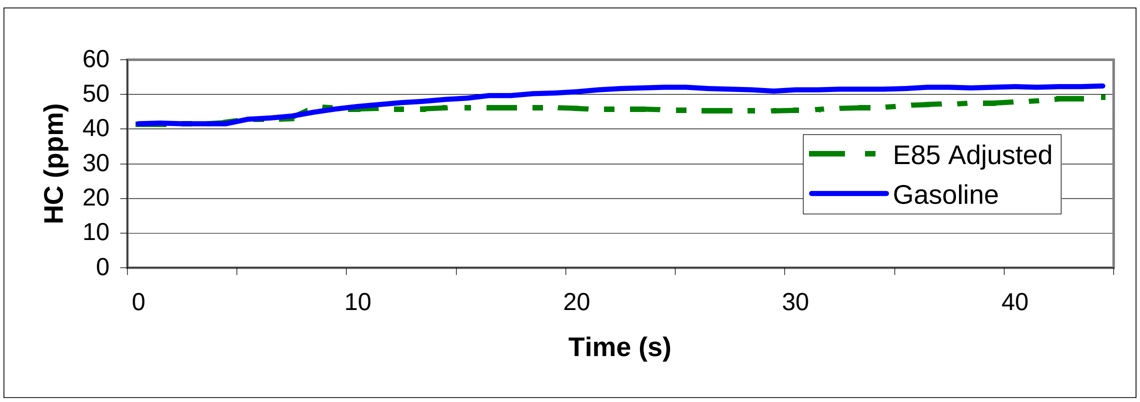


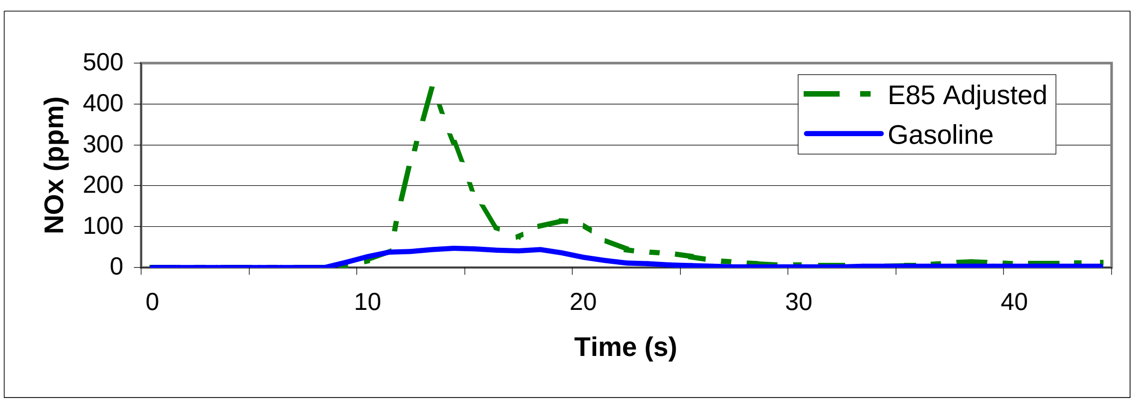
Appendix M; Individual emissions event

Caravan: Hard Acceleration from Ashe/Western stop and continuing at 45 mph



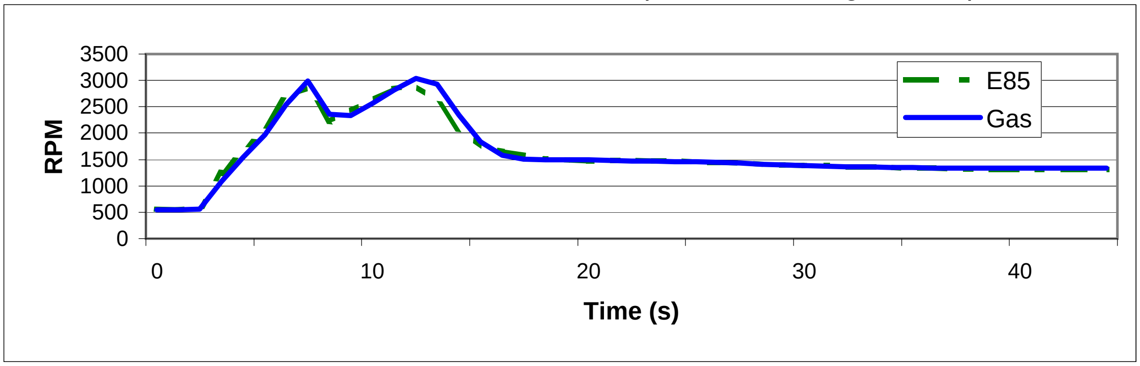


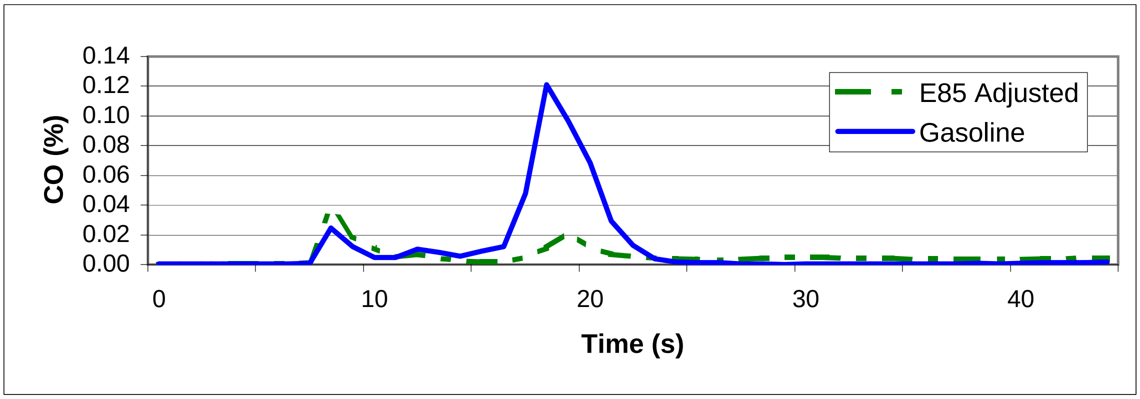


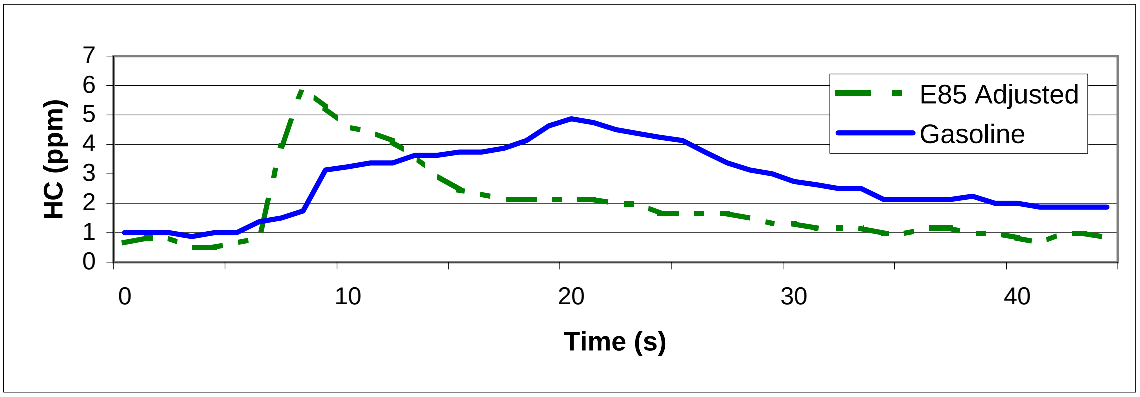


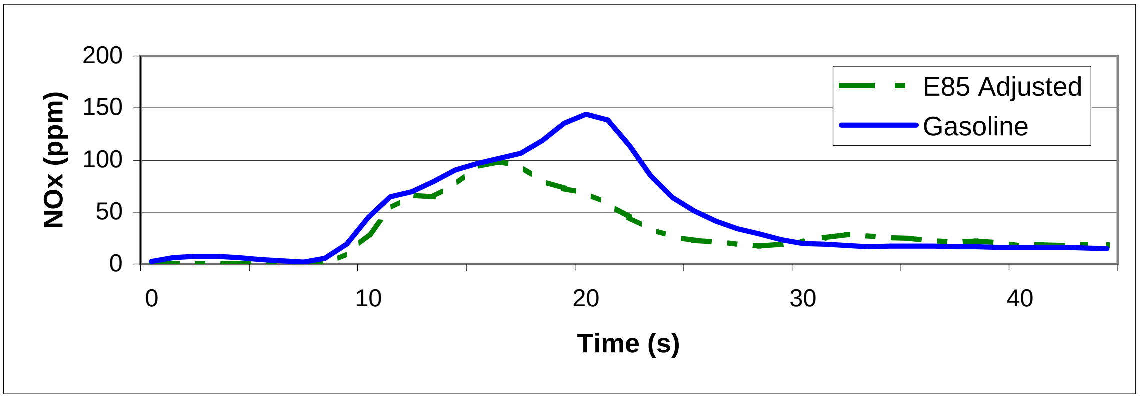
Appendix M; Individual emissions event

Tahoe: Hard Acceleration from Ashe/Western stop and continuing at 45 mph

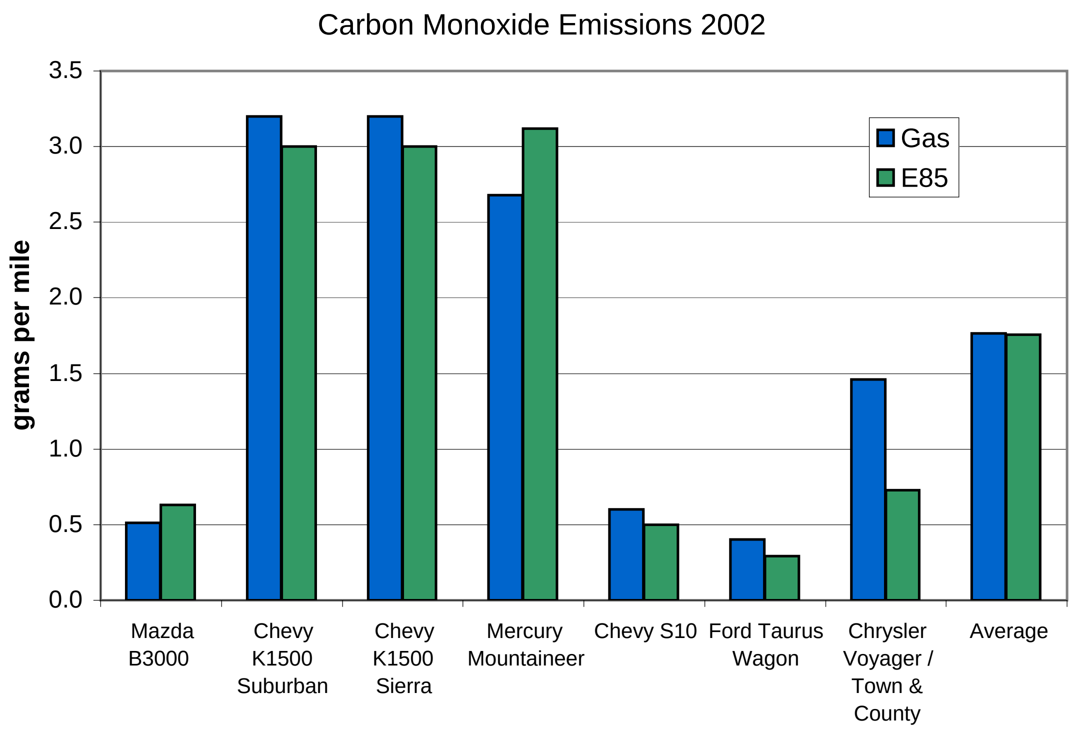


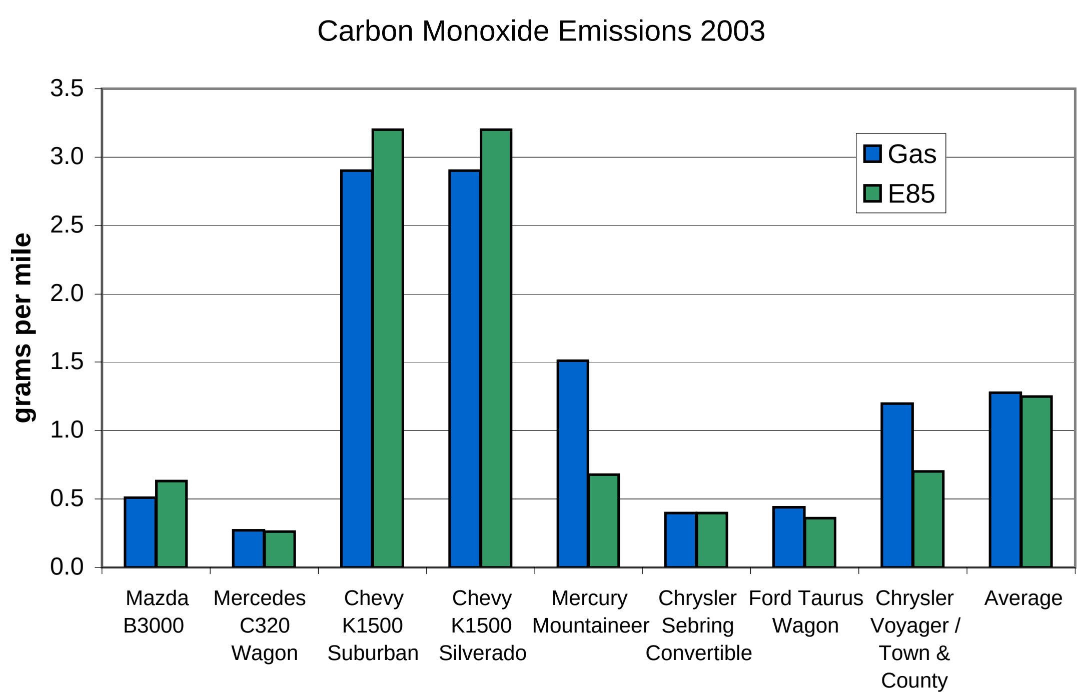




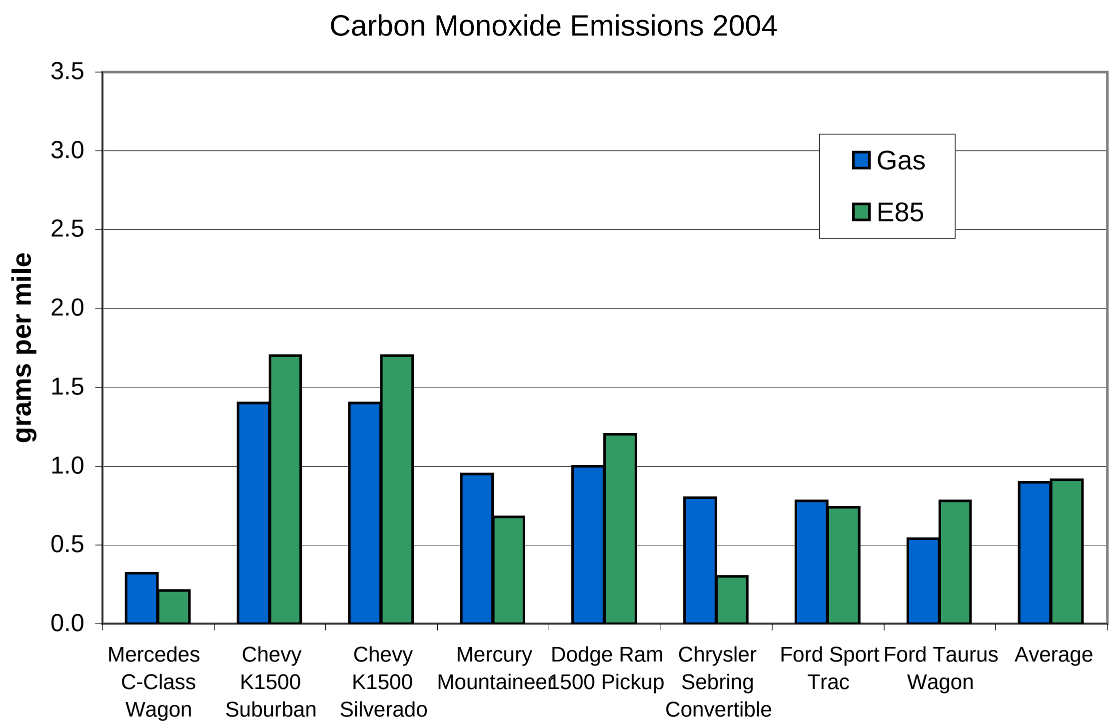


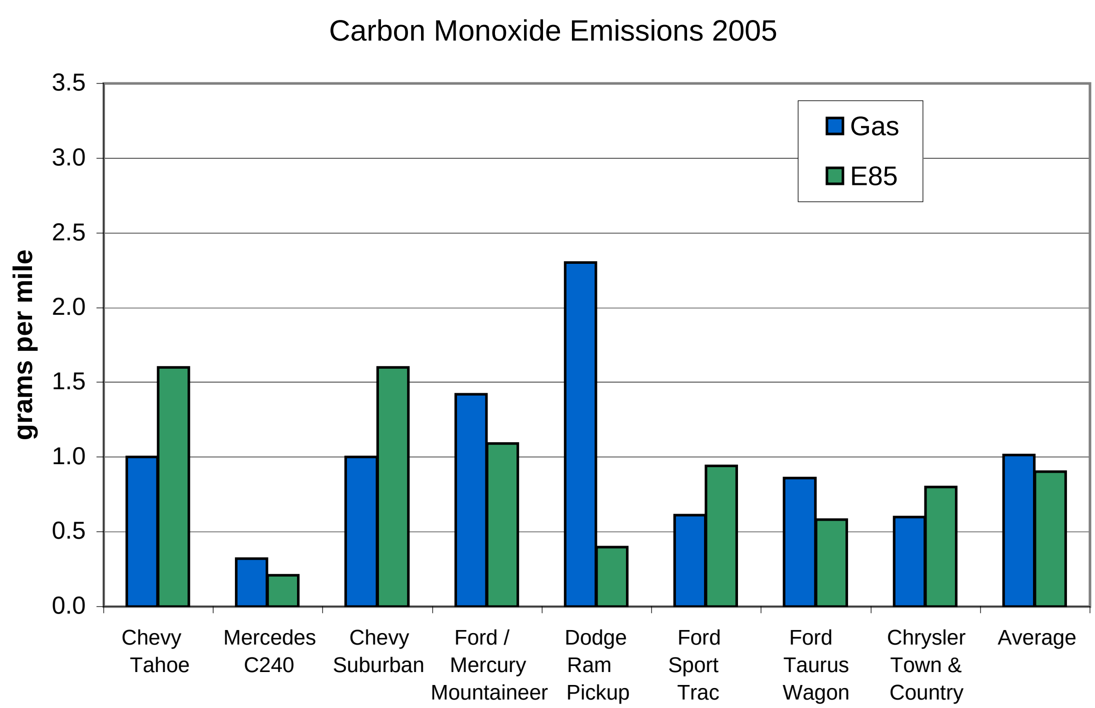
Appendix N: EPA's annual certification test results



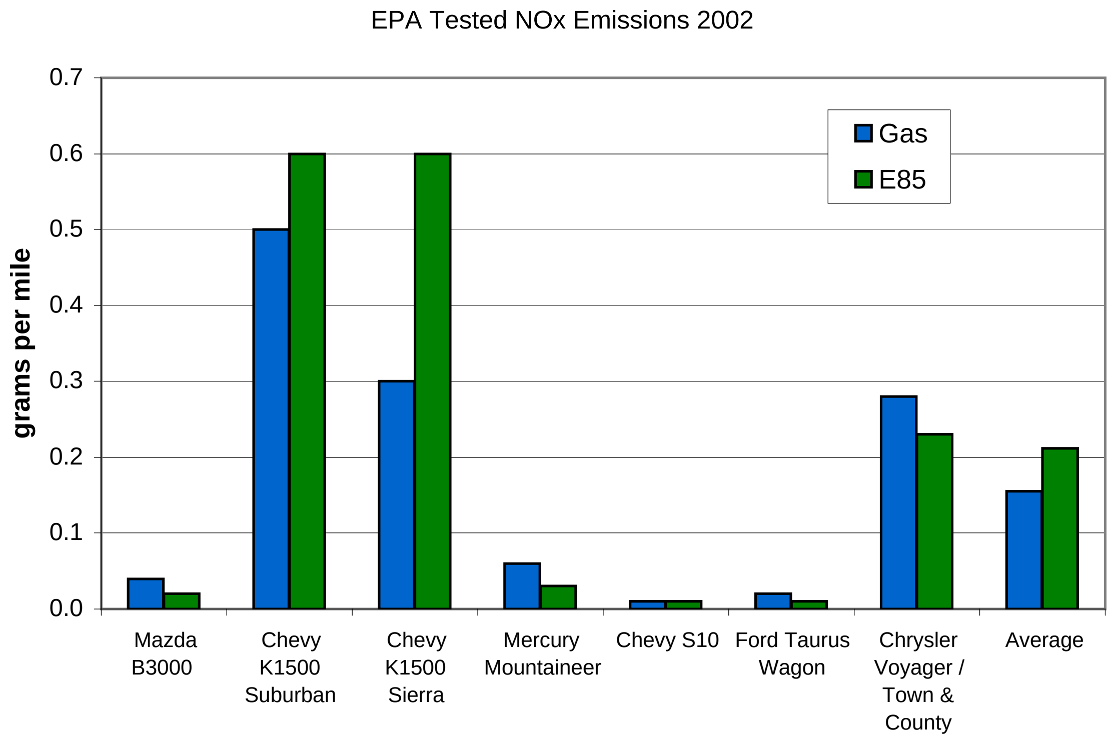


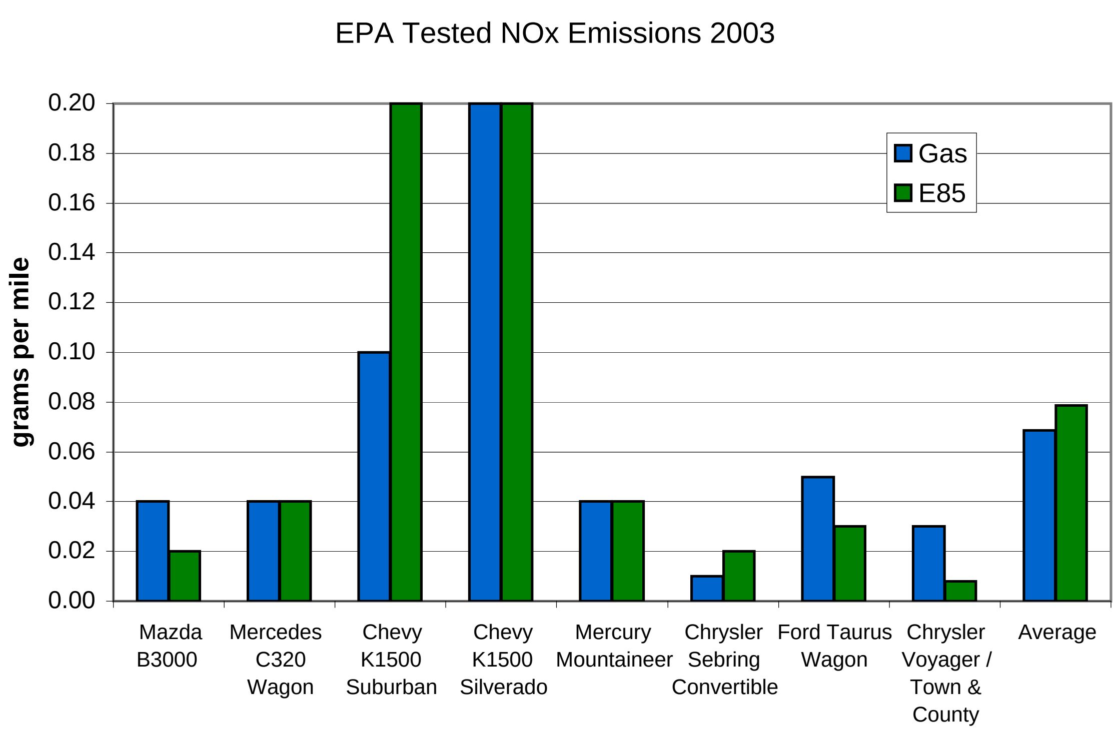
Appendix N: EPA's annual certification test results





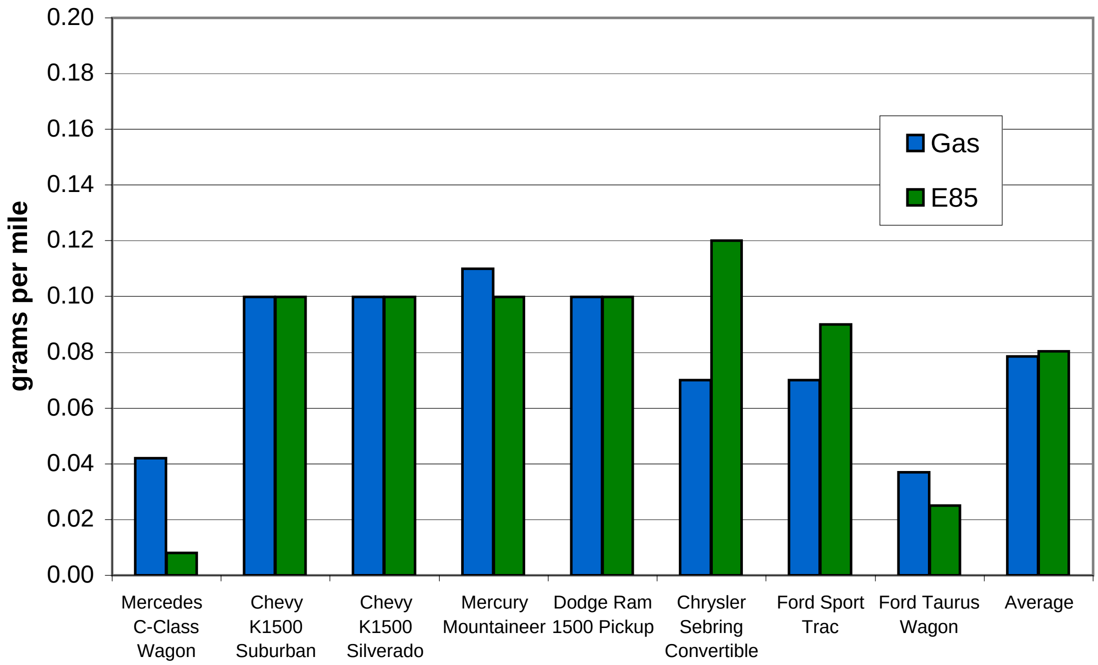
Appendix O: EPA's annual certification test results



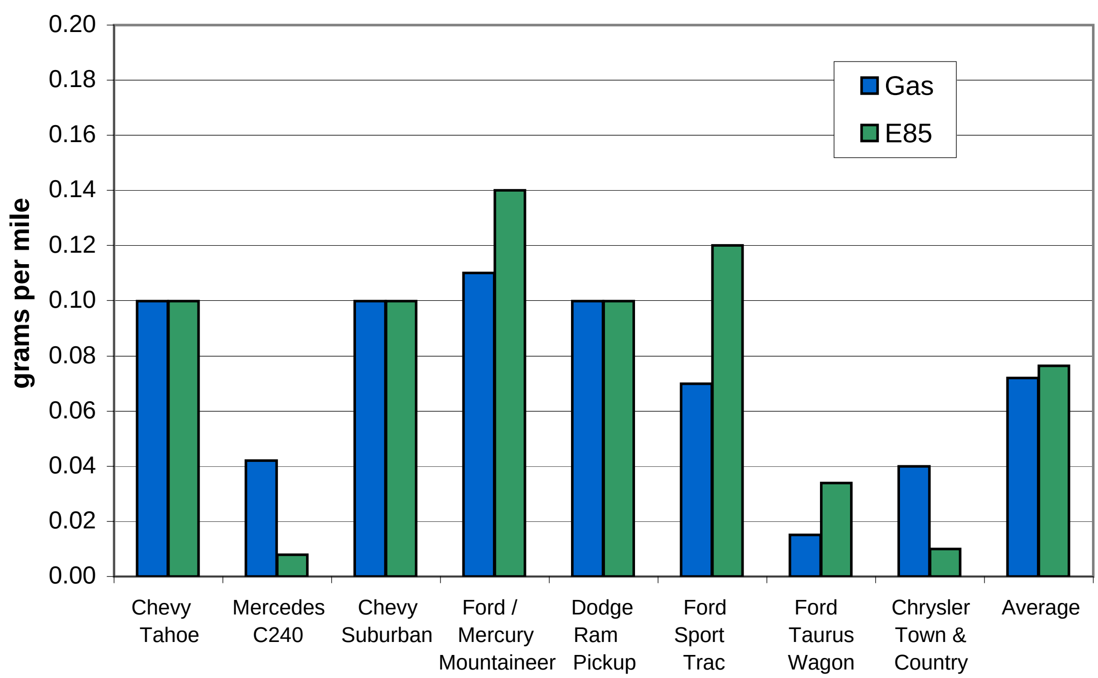


Appendix O: EPA's annual certification test results

EPA Tested NOx Emissions 2004



EPA Tested NOx Emissions 2005



Appendix P: Awareness survey - first draft

Hello, my name is Bryan Roy and I am a mechanical engineering graduate student at North Carolina State University. I am doing a research project with the North Carolina Solar Center on alternative fuels for vehicles and would like to ask you a few short questions for a survey. It will only take about 5 minutes, would you be willing to participate?

1. Confirm name and residence (city).

2. What is the make, model, and year of the vehicle that you drive?

3. Do you have any other vehicles?

4. What fuel (grade) do you typically use?

5. Are you concerned about the state of fuel in the US? (Very, somewhat, not really)

6. What is your biggest concern related to fuel? (rising cost, limited supply, dependence on other countries, pollution)

7. If available, would you buy an alternative fuel that is made in the US from renewable resources and causes less pollution?

8. How much more would you be willing to pay more for that fuel? (5,10,20,30 cents per gallon)

9. If performance, cost and style were similar to conventional gasoline vehicles, would you choose to buy a new vehicle that would run on an alternative fuel?

10. Do you know if your vehicle can run on a fuel other than gasoline?

Thank you very much for participating in this research project. Just so you know, the vehicle that you own can run on an alternative fuel. That fuel is Ethanol, or E85. It can be made from many agricultural crops here in the US, the most common being corn. E85 is available in many Mid-west states and many North Carolina State vehicles currently run on this fuel. This project is part of a plan to install the first commercial E85 station in North Carolina, right here in Wake County. You will likely be contacted or notified again when that station is operational.

This survey is complete, but I would be more than happy to answer any questions or provide you more information about E85 if you are interested.

Thank you for taking the time to talk with me.

Appendix P: Awareness survey - second draft

Wake Technical Community College
E-85 Infrastructure Project
Awareness Survey

Hello, my name is Bryan Roy and I am a graduate student at North Carolina State working on a research project with the North Carolina Solar Center on alternative fuels for vehicles. Your name was randomly selected from a listing of vehicle registration in Wake County. I would like to ask you a few short questions for a survey that will only take about 5 minutes. Are you willing to participate?

Questions	Answers	
1. Do you still own a YEAR-MAKE-MODEL?	Yes - continue with survey	
	No - politely end the survey	
2. How many miles do you typically drive this vehicle each year?	Record Value	
3. What fuel (grade) do you typically use?	Regular	1
	Mid-grade	2
	Premium	3
4. How concerned are you about the state of fuel in the US?	Very	1
	Moderately	2
	Somewhat	3
	Not at all	4
5. What is your biggest concern related to fuel?	Rising cost	1
	Limited Supply	2
	Dependance	3
	Pollution	4
6. If available, would you buy an alternative fuel that is made in the US from renewable resources and causes less pollution?	Yes	1
	No	2
7. How much more per gallon would you be willing to pay more for that fuel?	5 cents	1
	10 cents	2
	20 cents	3
	30 cents	4
8. If performance, cost and style were similar to conventional gasoline vehicles, would you choose to buy a new vehicle that would run on an alternative fuel?	Yes	1
	No	2
gasoline?	Yes	1
	No	2
10. If yes, how much of a factor was this in deciding to purchase this vehicle?	Big	1
	Small	2
	Not at all	3

Thank you very much for participating in this research project. Just so you know (or As you know), the vehicle that you own can run on an alternative fuel. That fuel is Ethanol, or E85. It can be made from many agricultural crops here in the US, the most common being corn. E85 is available in many Mid-west states and many North Carolina State vehicles currently run on this fuel. This project is part of a plan to install the first commercial E85 station for North Carolina, right here in Wake County. You will likely be contacted or notified again when that station is operational.

This survey is complete, but I would be more than happy to answer any questions or provide you more information about E85 if you are interested.

Thank you for taking the time to talk with me.

Appendix Q: Awareness survey - final draft

Wake Technical Community College
E-85 Infrastructure Project
Awareness Survey

NORTH CAROLINA SOLAR CENTER

Hello, my name is Bryan Roy and I am a graduate student at NC State working on a research project with the North Carolina Solar Center on alternative fuels. Would you mind answering ten questions for a survey that will only take a few minutes?

For your information, your name was randomly selected from a vehicle registration list for Wake County. All personal information will be kept strictly confidential.

Questions	Answers	
1. Do you still own a YEAR-MAKE-MODEL?	Yes - continue with survey	
	No - politely end the survey	
2. What fuel (grade) do you typically use?	Regular	1
	Mid-grade	2
	Premium	3
3. Can your vehicle run on any fuel other than gasoline?	Yes	1
	No	2
	Doesn't know	3
4. If yes, how much of a factor was this in deciding to purchase this vehicle?	Big	1
	Small	2
	Not at all	3
5. How concerned are you about the state of fuel in the US?	Very	1
	Moderately	2
	Somewhat	3
	Not at all	4
6. What is your biggest concern related to fuel?	Rising cost	1
	Limited Supply	2
	Dependance	3
	Pollution	4
7. If available, would you buy an alternative fuel that is made in the US from renewable resources and causes less pollution?	Yes	1
	No	2
8. How much more per gallon would you be willing to pay more for that alternative fuel?	None	1
	5 cents	2
	10 cents	3
	20 cents or more	4
9. If performance, cost and style were similar to conventional gasoline vehicles, would you choose to buy a new vehicle that would run on an alternative fuel?	Yes	1
	No	2

Thank you very much for participating in this research project. Just so you know (or As you know), the vehicle that you own can run on an alternative fuel. That fuel is Ethanol, or E85. It can be made from many agricultural crops here in the US, the most common being corn. E85 is available in many Mid-west states and many North Carolina State vehicles currently run on this fuel. This project is part of a plan to install the first commercial E85 station for North Carolina, right here in Wake County. You will likely be contacted or notified again when that station is operational.

This survey is complete, but I would be more than happy to answer any questions or provide you more information about E85 if you are interested.

Thank you for taking the time to talk with me.

Appendix R: Application for survey exception from NCSU IRB

North Carolina State University
Institutional Review Board for the Use of Human Subjects in Research
REQUEST FOR ADMINISTRATIVE REVIEW (for exempt studies)

Title of Project: *E-85 Infrastructure Awareness Survey*
Principal Investigator: *Bryan Roy* Department: *NC Solar Center / Mechanical Engineering*
Source of Funding: *Wake Technical Community College / NC State Energy Office*
Campus Address (box number): *7401*
Email: *bryan_roy@ncsu.edu* Phone: *513-7327* Fax: *515-5778*
RANK: ☐ Faculty

☒ Student: ☐ Undergraduate; ☒ Masters; or ☐ PhD

☐ Other (specify):

If rank is *not* faculty, name of faculty sponsor overseeing the research: *Dr. Alex Hobbs*
Faculty Sponsor email: *alex_hobbs@ncsu.edu* Phone: *515-6366* Fax: *515-5778*

Principal Investigator's Statement of Responsibility

As the principal investigator, my signature testifies that I have read and understood the University Policy and Procedures for the Use of Human Subjects in Research. I assure the Committee that all procedures performed under this project will be conducted exactly as outlined in the Proposal Narrative and that any modification to this protocol will be submitted to the Committee in the form of an amendment for its approval prior to implementation.

____ __________________
Signature of Principal Investigator* Date

Faculty Sponsor's Statement of Responsibility

As the faculty sponsor, my signature testifies that I have reviewed this application thoroughly and will oversee the research in its entirety. I hereby acknowledge my role as the principal investigator of record.

____ __________________
Signature of Faculty Sponsor* Date
**Studies submitted electronically are considered to be signed via an electronic signature*

PLEASE COMPLETE AND DELIVER TO:
Institutional Review Board, Box 7514, NCSU Campus (Leazer Hall Lower Level)
****

For IRB office use only

☐ Exemption Granted ☐ Not Exempt, full protocol necessary

Exempt Under: ☐ b.1 ☐ b.2 ☐ b.3 ☐ b.4 ☐ b.6

____ __________________
IRB Reviewer Date

Appendix R: Application for survey exception from NCSU IRB (con't)

Project Description Describe your project in the space provided below. Include information on how human subjects will be involved, what the procedure will be, if and how identifiers will be collected, and why your study qualifies for exemption under one of the categories listed below. If a survey instrument, interview guides, or other documents that will be used in the study are available, attach them to this form.

This awareness survey will involve calling randomly selected participants from a list of Flex-Fueled Vehicles (run on E85) supplied by the Department of Air Quality through the DMV. The questions included on the attached survey will be asked of the owner provided they still own the vehicle in question. Presentations and representations of the data collected in the survey will only contain statistical values and names of participants will not be disclosed.

Exemption Category: *(Choose only one of the following that specifically matches the characteristics of your study that make this project exempt)*

1. Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

X 2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

3. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

4. Research, involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

5. Not applicable

6. Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration, or approved by the Environmental Protection Agency, or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

Appendix R: Survey exception approval letter

North Carolina State University is a land-grant university and a constituent institution of The University of North Carolina

Office of Research and Graduate Studies

NC STATE UNIVERSITY

Sponsored Programs and Regulatory Compliance
Campus Box 7514
1 Leazar Hall
Raleigh, NC 27695-7514
919.515.7200
919.515.7721 (fax)

From: Debra A. Paxton, Regulatory Compliance Administrator
North Carolina State University Institutional Review Board

Date: February 15, 2005

Project Title: E-85 Infrastructure Awareness Survey

IRB#: 031-05-2

Dear Mr. Roy:

The research proposal named above has received administrative review and has been approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101.b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations.

   For NCSU projects, the Assurance Number is: FWA00003429; the IRB Number is: IRB00000330

2. Review de novo of this proposal is necessary if any significant alterations/additions are made.

Please provide your faculty sponsor with a copy of this letter. Thank you.

Sincerely,

Debra Paxton
NCSU IRB

Appendix S: NCSU statistical consulting report

Client: Bryan Roy
Consultant: Kris Chowning
Faculty Advisor: Dr. Cavell Brownie

Client's Information
Name: Bryan Roy
Status: Graduate student
Department: MAE
E-mail: beroy2@ncsu.edu

Objective
Mr. Roy intends to conduct a telephone survey of individuals in Wake County who own vehicles that can be run on an alternative fuel (i.e., Ethanol or E85). This project is part of a plan to install the first commercial E85 station in Wake County. The primary purpose of the survey is to assess whether or not current owners of these respective vehicles would choose E85 over conventional petroleum fuel if given the option. Mr. Roy sought assistance regarding (1) the determination of an appropriate sample size for the survey, (2) inclusion of stratification in the survey, and (3) general feedback about the structure of the survey (e.g., question content, question order, etc.).

Description
The survey questionnaire consists of 10 questions of which the responses from 9 questions would be characterized as discrete data: (1) binomial (e.g., yes/no questions) or (2) multinomial (Not at all/Somewhat/Moderately/Very). The response from one question would be characterized as continuous data since it is a measure of estimated annual vehicle mileage.

With respect to the questions that generate discrete data, Mr. Roy is interested in estimating population proportions (e.g., proportion of vehicle drivers who would purchase alternative fuel, or proportion of vehicle drivers who would be willing to pay 20 cents more per gallon for alternative fuel). Each population proportion that is estimated is desired to have a margin of error of ± 0.05. Because none of these proportions of interest could be estimated a priori, it was decided that a worst-case scenario should be assumed (i.e., p=0.5). In addition, a standard significance level of $\alpha = 0.05$ was chosen so that 95% confidence intervals could be constructed. With regard to the target population size and the sampling frame, Mr. Roy had obtained a list of all vehicles (and their owners) currently registered in Wake County whose engines can run on alternative fuel. This list consists of 6600 vehicles (i.e., N=6600). After obtaining the sample, he will look up phone numbers in the telephone directory.

Analysis

If we ignore the finite population correction factor (since n is much smaller than N), the formula used to determine the necessary sample size for the survey is as follows:

$$n = \frac{z_{\alpha/2}^{2} p(1-p)}{d^{2}}$$

where

$z_{\alpha/2} = 1.96$

p=0.5

d=0.05 (maximum allowable difference between the estimate and the true value)

Substituting these values into the above formula yields a sample size of n=384.16. As a result, a sample size of roughly 400 was recommended. This sample size should ensure that estimates of the desired population proportions associated with binomial response categories (i.e., yes/no) can be made with a 95% confidence level. If Mr. Bryan is interested in simultaneously estimating several proportions for those questions that have multinomial response categories (e.g., question 7), the probability of making a Type II error for this sample size would be approximately $\alpha = 0.10$. So, one would still be 90% confident that the true proportion is within ± 0.05 of the estimate.

The population of alternative fuel vehicles can be stratified on the basis of vehicle make (e.g., Ford, Mazda) and model (e.g., Explorer, Taurus). However, because the number of subgroups was large and the research questions of interest did not appear to be related to these particular subgroups, stratification was not recommended. It is possible that some information might be gained about these subgroups after the survey is completed using post-stratification methods.

A 95% confidence interval could easily be constructed for the mean annual number of miles driven per vehicle (Question 2) after the survey is completed. Minimum sample size needed to ensure that one's estimate is within $\pm d$ miles cannot be computed in advance without knowing (an estimate of) the sample variance. Because this question was not considered to be of primary interest by Mr. Roy, it did not affect the final sample size recommendation for the survey.

Only minor suggestions were offered to Mr. Roy regarding the survey questionnaire itself in order to ensure that response categories were exhaustive and question order did not create sample bias.

Reference:

Thompson, Steven K. (2002). Sampling (2nd Edition). New York: Wiley & Sons, Inc., p. 39-43.

Appenidx T: Complete awareness survey responses

#	YEAR	MAKE	MODEL	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Additional Comments
1	2004	CHEVROLET	TAHOE				1	0	1	4	1	No FFV, Q6; All of the above
2	2003	CHEVROLET	YUKON				2	3	1	4	1	Never owned that vehicle
3	1998	CHRYSLER	CARAVAN				4		1	1	1	Doesn't own that vehicle
4	1999	CHRYSLER	PLY. VOYAGER				2	2	0	3	1	Doesn't own it, Q7; possibly
5	1998	CHRYSLER	CARAVAN				2	3	1	4	1	Sold the car
6	1998	CHRYSLER	CARAVAN				3	1	1	2	2	Sold the Caravan
7	1999	CHRYSLER	PLY. VOYAGER				1	3	1	3	1	Has another Chrysler van
8	1998	CHRYSLER	CARAVAN				2	3	1	4	1	No longer owns vehicle
9	2004	CHEVROLET	SUBURBAN				1	3	1	1	1	Doesn't own that vehicle
10	2003	CHEVROLET	SUBURBAN				2	3	1	3	1	Doesn't own the vehicle
11	2000	CHRYSLER	CARAVAN				2	3	1	3	1	No longer own the vehicle
12	1998	CHRYSLER	CARAVAN				2	1	0	2	1	Sold it, Q7; if it worked in theirs
13	2002	CHEVROLET	TAHOE				2	3	1	3	1	does not own that vehicle
14	1998	CHRYSLER	CARAVAN				1	4	1	4	1	Sold the vehicle
15	2000	CHRYSLER	CARAVAN				1	3	1	4	1	No longer owns the vehicle
16	1998	CHRYSLER	CARAVAN				1	1	1	4	0	Doesn't own it, Q9; maybe
17	2003	CHEVROLET	SUBURBAN				1	1	1	3	1	Doesn't own the vehicle
18	1999	CHRYSLER	CARAVAN				2	1	1	1	1	Doesn't own the vehicle
19	2002	CHEVROLET	S-10				2	2	1	4	1	Does not own the vehicle
20	1999	CHRYSLER	PLY. VOYAGER				1	2	1	4	1	sold the vehicle
21	2000	CHEVROLET	SONOMA	1	3		1	3	1	1	1	
22	2004	CHEVROLET	TAHOE	1	2		1	4	1	4	1	
23	2004	FORD	EXPLORER	1	2		3	2	1	4	1	
24	1999	CHRYSLER	CARAVAN	1	2		1	2	1	4	1	
25	2004	CHEVROLET	SUBURBAN	1	2		2	1	1	2	1	
26	1993	CHEVROLET	SILVERADO	1	1	3	1	1	1	2	1	
27	2003	CHEVROLET	TAHOE	1	2		2	3	1	1	1	
28	2004	CHEVROLET	TAHOE	1	1	2	1	1	1	1	1	knew it ran on ethanol but didn't consider it an alternative fuel
29	2000	CHEVROLET	S-10	1	2		4		1	2	2	
30	2003	FORD	EXPLORER	1	2		4		1	3	1	
31	1998	CHRYSLER	CARAVAN	1	3		3		1	1	1	
32	2003	CHEVROLET	YUKON	1	3		2	3	1	2	1	
33	1999	CHRYSLER	CARAVAN	1	2		2	1	1	3	1	
34	2002	CHEVROLET	SUBURBAN	1	2		4		1	4	1	
35	2005	CHEVROLET	SUBURBAN	1	1	3	4		1	3	1	
36	2002	CHEVROLET	SUBURBAN	1	2		2	1	1	2	1	
37	2002	CHEVROLET	SUBURBAN	1	2		3	4	1	4	1	
38	1998	CHRYSLER	PLY. VOYAGER	1	2		2	1	1	3	1	
39	2003	CHEVROLET	SUBURBAN	1	2		1	0	1	1	0	Q6; more drilling in Alaska
40	1999	FORD	RANGER	1	2		2	3	1	1	1	
41	2002	CHEVROLET	SUBURBAN	1	2		2	1	1	1	2	
42	2004	CHEVROLET	YUKON	1	3		3	0	1	1	1	Q6; administration
43	2000	CHEVROLET	S-10	1	2		2	3	1	2	1	
44	2003	CHRYSLER	STRATUS	1	2		2	4	1	4	1	
45	2003	CHEVROLET	TAHOE	1	2		4		1	4	1	
46	2000	CHRYSLER	CARAVAN	1	2		2	1	1	1	1	
47	1998	CHRYSLER	CARAVAN	1	3		3	1	1	4	1	
48	2004	CHEVROLET	YUKON	1	2		2	2	1	2	1	
49	2002	FORD	EXPLORER	1	2		2	1	1	4	1	
50	2000	CHEVROLET	SONOMA	1	3		2	1	1	3	1	
51	2003	CHEVROLET	TAHOE	1	2		2	3	1	3	1	

Appenidx T: Complete awareness survey responses (con't)

#	YEAR	MAKE	MODEL	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Additional Comments
52	2004	CHEVROLET	SUBURBAN	1	2		1	3	1	4	1	
53	2000	CHRYSLER	CARAVAN	1	3		2	1	1	0	2	
54	2003	CHEVROLET	SUBURBAN	1	2		2	3	1	3	1	
55	2002	CHEVROLET	SUBURBAN	1	3		3	3	1	3	1	
56	2003	CHEVROLET	SUBURBAN	1	3		1	3	1	3	0	Q9 if they were in big sizes
57	2004	CHEVROLET	TAHOE	1	2		1	3	1	4	1	
58	2004	CHEVROLET	TAHOE	1	2		1	3	1	2	1	
59	2003	FORD	EXPLORER	1	3		1	1	1	1	1	
60	1999	CHRYSLER	PLY. VOYAGER	1	2		2	1	0	2	0	Q7and 9 are perhaps
61	2002	CHEVROLET	SUBURBAN	1	2		2	1	1	2	2	
62	2004	CHEVROLET	TAHOE	1	2		3	4	1	3	1	
63	2002	CHEVROLET	YUKON	1	1	3	1	3	1	3	1	
64	1999	FORD	RANGER	1	1	3	3	2	1	4	1	
65	2004	CHEVROLET	YUKON	1	2		3	4	1	3	1	
66	2004	CHEVROLET	SUBURBAN	1	2		1	2	1	1	1	
67	2004	FORD	TAURUS	1	3		2	1	0	0	1	Q7&8 Doesn't know
68	2000	CHRYSLER	TOWN & COUNTRY	1	2		3	0	1	4	1	Q6 all of the above
69	1998	CHRYSLER	CARAVAN	1	3		2	3	1	3	1	
70	2003	CHEVROLET	TAHOE	1	2		1	3	1	4	1	
71	2003	FORD	EXPLORER	1	3		2	1	2		2	
72	1998	CHRYSLER	CARAVAN	1	3		1	2	1	3	1	
73	2003	CHEVROLET	SUBURBAN	1	2		2	3	1	3	1	
74	1999	CHRYSLER	PLY. VOYAGER	1	1	3	2	3	1	4	1	Read about E85 in the manual
75	1998	CHRYSLER	PLY. VOYAGER	1	3		3	3	1	3	1	Q6; Support the farmers
76	1999	CHRYSLER	CARAVAN	1	1	3	1	1	1	1	1	
77	2003	CHEVROLET	TAHOE	1	2		1	4	1	3	1	
78	2002	CHEVROLET	YUKON	1	1	3	2	3	1	1	1	
79	2004	CHEVROLET	SUBURBAN	1	2		3	3	1	4	1	
80	2004	CHEVROLET	YUKON	1	2		2	1	1	2	1	
81	2004	CHEVROLET	SUBURBAN	1	1	3	1	1	1	1	1	
82	2002	CHEVROLET	TAHOE	1	1	3	1	3	1	4	1	
83	1998	CHRYSLER	PLY. VOYAGER	1	2		2	4	1	3	1	
84	2004	CHEVROLET	SUBURBAN	1	2		1	1	1	1	1	
85	2003	CHEVROLET	YUKON	1	3		3	1	1	1	1	
86	2004	FORD	EXPLORER	1	2		1	3	1	4	1	
87	2000	CHRYSLER	CARAVAN	1	2		1	1	1	1	1	
88	1999	CHRYSLER	CARAVAN	1	1	2	2	3	1	1	1	
89	2004	CHEVROLET	SUBURBAN	1	2		1	4	1	4	1	
90	2003	CHEVROLET	TAHOE	1	2		1	3	1	3	1	
91	2004	CHEVROLET	YUKON	1	2		2	1	1	1	1	
92	1998	CHRYSLER	PLY. VOYAGER	1	3		2	1	1	1	1	
93	2000	CHRYSLER	CARAVAN	1	3		4		0	0	0	Q7-9; Didn't know
94	1998	CHRYSLER	CARAVAN	1	1	3	2	4	1	3	1	
95	1999	CHRYSLER	PLY. VOYAGER	1	2		1	1	1	1	1	
96	2003	CHEVROLET	SUBURBAN	1	3		2	1	1	3	1	
97	2003	CHEVROLET	TAHOE	1	2		1	1	1	1	1	
98	2002	CHEVROLET	TAHOE	1	2		2	4	1	1	1	
99	1999	CHRYSLER	PLY. VOYAGER	1	2		3	1	1	1	1	
100	2003	CHEVROLET	TAHOE	1	2		2	2	1	2	1	
101	2004	CHEVROLET	YUKON	1	3		4	1	1	1	1	
102	2001	CHEVROLET	S-10	1	3		1	2	1	0	1	Q8; too hard to know
103	1995	CHEVROLET	SILVERADO	1	3		2	1	1	1	1	Traded in for a 2001

Appenidx T: Complete awareness survey responses (con't)

#	YEAR	MAKE	MODEL	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Additional Comments
104	2002	CHEVROLET	SUBURBAN	1	2		2	1	1	1	1	
105	2003	CHEVROLET	TAHOE	1	2		1	2	1	4	1	
106	2004	CHEVROLET	YUKON	1	2		1	1	1	2	1	
107	1998	CHRYSLER	CARAVAN	1	2		1	1	1	2	1	
108	2002	CHEVROLET	YUKON	1	2		2	4	1	4	1	
109	2004	CHEVROLET	SUBURBAN	1	3		2	1	1	2	1	
110	2003	CHEVROLET	SUBURBAN	1	2		1	3	1	4	1	
111	2003	CHEVROLET	TAHOE	1	3		3	3	1	1	1	
112	1998	CHRYSLER	CARAVAN	1	1	3	2	3	1	4	1	
113	1999	CHRYSLER	PLY. VOYAGER	1	2		3	2	1	1	1	
114	2002	CHEVROLET	YUKON	1	3		2	1	1	1	2	
115	2000	CHRYSLER	CARAVAN	1	2		2	3	1	3	1	
116	2002	CHEVROLET	S-10	1	1	3	1	1	1	1	2	
117	2003	CHEVROLET	SUBURBAN	1	2		1	1	1	3	1	
118	2000	CHEVROLET	SONOMA	1	2		2	1	1	2	1	
119	2002	CHEVROLET	SUBURBAN	1	2		2	3	1	4	1	
120	2004	FORD	EXPLORER	1	2		1	1	1	1	1	
121	2004	FORD	EXPLORER	1	2		1	1	1	1	1	
122	2004	CHEVROLET	TAHOE	1	1	2	1	4	1	4	1	
123	2003	CHEVROLET	YUKON	1	2		2	1	1	1	1	
124	2004	CHEVROLET	TAHOE	1	3		3	1	1	2	0	Q9 maybe
125	2002	CHEVROLET	SUBURBAN	1	3		4		1	2	1	
126	2004	CHEVROLET	SILVERADO	1	2		1	3	1	1	1	
127	2003	CHEVROLET	SUBURBAN	1	2		2	3	1	3	1	
128	1998	CHRYSLER	PLY. VOYAGER	1	2		2	0	1	4	1	Q6; larger vehicles
129	2002	CHEVROLET	SUBURBAN	1	2		2	1	1	4	1	
130	2003	CHEVROLET	SUBURBAN	1	2		3	3	1	4	2	
131	2003	CHEVROLET	TAHOE	1	2		1	3	1	4	1	
132	2000	CHRYSLER	CARAVAN	1	3		4		1	1	1	
133	2002	CHEVROLET	TAHOE	1	3		1	1	1	3	1	
134	2002	CHEVROLET	TAHOE	1	2		1	1	1	1	1	
135	2004	CHEVROLET	TAHOE	1	2		2	1	2		1	
136	2003	FORD	TAURUS	1	1	2	1	1	1	4	1	
137	2000	CHRYSLER	TOWN & COUNTRY	1	1	3	2	1	1	1	1	
138	2003	CHEVROLET	YUKON	1	2		3	1	1	2	1	
139	2001	CHEVROLET	S-10	1	2		2	2	1	2	1	
140	2004	CHEVROLET	SUBURBAN	1	3		2	1	1	3	1	
141	2003	CHEVROLET	TAHOE	1	3		1	3	1	4	1	
142	2004	FORD	TAURUS	1	2		1	3	1	4	0	Q9; questionable
143	2000	CHRYSLER	CARAVAN	1	2		2	1	1	1	0	Q9; doesn't know
144	2002	CHEVROLET	SUBURBAN	1	2		2	3	1	1	1	
145	2002	CHEVROLET	S-10	1	2		2	1	1	2	2	
146	2004	CHEVROLET	TAHOE	1	1	2	1	0	1	1	1	Q6; there are no alternatives
147	2004	CHEVROLET	TAHOE	1	3		1	1	0	1	2	Q7; possibly
148	2002	CHEVROLET	TAHOE	1	2		1	3	1	3	1	
149	2003	FORD	EXPLORER	1	3		1	4	1	3	1	
150	2004	CHEVROLET	TAHOE	1	2		1	1	1	1	0	Q9; if fuel doesn't cost more
151	2000	CHRYSLER	CARAVAN	1	3		3	4	1	4	1	
152	2003	CHEVROLET	TAHOE	1	3		1	1	1	1	1	
153	2004	FORD	EXPLORER	1	3		2	4	1	3	1	
154	2004	CHEVROLET	TAHOE	1	3		3	2	1	1	1	
155	2004	CHEVROLET	SUBURBAN	1	1	3	1	4	1	3	1	

Appenidx T: Complete awareness survey responses (con't)

#	YEAR	MAKE	MODEL	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Additional Comments
156	2003	CHEVROLET	TAHOE	1	2		2	1	1	3	1	
157	2004	CHEVROLET	TAHOE	1	2		1	4	1	4	1	
158	2004	CHEVROLET	TAHOE	1	2		2	1	1	3	1	
159	1998	CHRYSLER	PLY. VOYAGER	1	2		2	1	0	1	2	Q7; would need more fuel info
160	2004	CHEVROLET	TAHOE	1	1	3	3	3	1	4	1	
161	2002	CHEVROLET	SUBURBAN	1	3		2	2	1	4	0	Q9; doesn't know
162	2003	CHRYSLER	STRATUS	1	2		2	1	1	2	1	
163	2003	CHEVROLET	TAHOE	1	2		1	2	1	2	1	
164	2003	CHEVROLET	SUBURBAN	1	2		2	3	1	3	1	Says it is not an FFV, from VIN
165	2003	CHEVROLET	TAHOE	1	2		1	2	1	4	1	
166	2002	CHEVROLET	SUBURBAN	1	2		1	1	1	1	1	
167	2000	CHRYSLER	CARAVAN	1	2		1	4	1	1	1	
168	2004	FORD	EXPLORER	1	2		1	3	1	4	1	
169	2001	CHEVROLET	S-10	1	2		1	1	1	2	1	
170	2003	CHEVROLET	YUKON	1	3		2	3	1	3	1	
171	1998	CHRYSLER	CARAVAN	1	2		1	1	1	4	1	
172	2004	CHEVROLET	YUKON	1	1	3	2	3	1	4	1	
173	2000	CHEVROLET	S-10	1	2		2	1	1	3	1	
174	2002	CHEVROLET	TAHOE	1	2		2	4	1	1	1	
175	2002	CHEVROLET	SUBURBAN	1	3		3	4	1	0	1	Q8; can't put a price on it
176	2002	CHEVROLET	TAHOE	1	2		1	1	1	2	2	
177	2003	CHEVROLET	YUKON	1	2		1	1	1	1	2	
178	2002	CHEVROLET	TAHOE	1	2		1	3	1	3	1	
179	2002	CHEVROLET	TAHOE	1	2		2	1	1	1	2	
180	1998	CHRYSLER	CARAVAN	1	1	3	1	3	1	4	1	
181	1998	CHRYSLER	CARAVAN	1	2		1	3	1	2	1	
182	2004	CHEVROLET	TAHOE	1	2		2	2	1	4	1	
183	2002	CHEVROLET	YUKON	1	2		3	1	1	1	0	Q9; not sure
184	2003	CHEVROLET	YUKON	1	2		3	2	2		2	Not ready for alternatives yet
185	1999	CHRYSLER	PLY. VOYAGER	1	2		3	4	1	4	1	
186	1999	CHRYSLER	CARAVAN	1	2		2	3	1	0	1	Q8; doesn't know
187	2002	FORD	EXPLORER	1	2		2	2	1	3	1	
188	2002	FORD	EXPLORER	1	2		2	2	1	1	1	
189	2003	CHEVROLET	TAHOE	1	1	1	1	2	1	2	1	
190	1998	CHRYSLER	CARAVAN	1	2		2	4	1	4	1	
191	2003	CHEVROLET	TAHOE	1	2		1	3	1	4	1	
192	2004	CHEVROLET	SUBURBAN	1	2		1	2	1	2	1	
193	2004	CHEVROLET	YUKON	1	1	3	2	3	1	3	1	
194	2003	CHEVROLET	SUBURBAN	1	1	3	1	2	1	2	1	
195	2004	CHEVROLET	SUBURBAN	1	3		3	3	1	3	1	
196	2003	CHEVROLET	YUKON	1	3		1	3	0	2	1	Q7; would need to know more
197	2004	CHEVROLET	TAHOE	1	3		2	1	1	1	1	
198	2003	CHEVROLET	TAHOE	1	2		2	2	1	4	1	
199	2002	CHEVROLET	TAHOE	1	2		1	3	1	4	1	
200	2004	CHEVROLET	YUKON	1	1	3	1	3	1	4	1	
201	2004	CHEVROLET	TAHOE	1	2		2	3	1	1	1	
202	2003	CHEVROLET	YUKON	1	1	3	1	3	1	4	1	
203	2001	FORD	TAURUS	1	3		3	1	0	0	0	Q7-9; doesn't know
204	2003	CHEVROLET	TAHOE	1	2		2	3	1	1	0	Q9; many factors to consider
205	2000	FORD	RANGER	1	1	3	3	3	1	1	1	
206	1999	CHRYSLER	PLY. VOYAGER	1	2		1	1	1	3	1	
207	2000	CHEVROLET	S-10	1	2		1	1	1	1	1	

Appenidx T: Complete awareness survey responses (con't)

#	YEAR	MAKE	MODEL	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Additional Comments
208	2004	CHEVROLET	SUBURBAN	1	3		3	3	1	4	2	
209	2002	CHEVROLET	TAHOE	1	3		1	1	1	1	1	
210	2004	FORD	EXPLORER	1	2		1	2	0	1	1	Q7; possibly
211	2000	FORD	TAURUS	1	1	2	1	3	1	2	2	
212	2003	CHEVROLET	SUBURBAN	1	2		1	1	1	2	1	
213	2003	CHEVROLET	TAHOE	1	2		2	2	0	2	2	Q7; possibly
214	1998	CHRYSLER	CARAVAN	1	2		2	1	1	2	1	
215	1999	CHRYSLER	PLY. VOYAGER	1	3		2	2	1	2	1	
216	2002	CHEVROLET	TAHOE	1	2		2	1	1	1	1	
217	2004	CHEVROLET	SUBURBAN	1	1	3	2	3	1	0	1	Q8; depends on fuel economy
218	2000	CHRYSLER	CARAVAN	1	1	2	2	3	0	4	1	Q7; depends on many factors
219	2004	CHEVROLET	TAHOE	1	2		1	3	1	3	1	
220	2003	CHEVROLET	SUBURBAN	1	3		2	3	1	3	1	
221	1999	FORD	RANGER	1	1	3	2	3	1	2	1	
222	2003	FORD	EXPLORER	1	2		1	1	1	4	1	
223	2003	CHEVROLET	SUBURBAN	1	2		1	3	1	4	1	
224	2003	CHRYSLER	SEBRING	1	2		2	1	1	1	1	
225	2000	CHRYSLER	CARAVAN	1	2		1	2	1	1	1	
226	2002	CHEVROLET	S-10	1	2		2	3	1	2	1	
227	2003	CHEVROLET	SUBURBAN	1	2		3	3	1	4	1	
228	2002	CHEVROLET	YUKON	1	2		1	1	1	2	1	
229	1999	CHRYSLER	PLY. VOYAGER	1	2		1	2	1	4	1	
230	2001	CHEVROLET	S-10	1	2		2	3	1	4	1	
231	1999	CHRYSLER	PLY. VOYAGER	1	2		2	1	1	4	1	
232	2001	CHEVROLET	S-10	1	3		2	1	1	4	1	
233	2003	CHEVROLET	YUKON	1	2		2	3	0	1	0	Q7&9; doesn't know
234	2001	FORD	TAURUS	1	1	3	1	4	1	2	1	
235	2003	CHEVROLET	SUBURBAN	1	3		1	2	1	1	1	
236	2000	CHEVROLET	S-10	1	3		1	3	1	1	1	
237	2002	CHEVROLET	TAHOE	1	3		2	1	1	4	1	
238	2000	FORD	TAURUS	1	2		3	1	1	2	0	Q9; Possibly
239	1998	CHRYSLER	PLY. VOYAGER	1	2		2	1	1	1	1	
240	2004	CHEVROLET	TAHOE	1	2		3	1	1	2	1	
241	1999	CHRYSLER	PLY. VOYAGER	1	2		1	2	1	4	1	
242	2003	CHEVROLET	TAHOE	1	2		3	4	1	4	1	
243	2003	CHEVROLET	TAHOE	1	2		2	1	1	2	0	Q9; possibly
244	1998	CHRYSLER	PLY. VOYAGER	1	1	3	1	1	1	1	1	
245	2003	CHEVROLET	SUBURBAN	1	1	3	2	1	1	1	1	
246	2002	CHEVROLET	SUBURBAN	1	2		2	3	1	3	1	
247	2003	CHEVROLET	TAHOE	1	2		1	4	1	3	1	
248	2004	CHEVROLET	YUKON	1	2		1	1	1	1	1	
249	2003	CHEVROLET	TAHOE	1	2		2	2	1	4	1	
250	2004	CHEVROLET	YUKON	1	2		1	1	1	1	1	
251	1998	CHRYSLER	CARAVAN	1	3		1	2	1	1	1	
252	2003	CHEVROLET	SUBURBAN	1	2		1	4	1	4	0	Q9; Maybe, supply is a concern
253	2003	CHRYSLER	SEBRING	1	2		2	1	1	3	1	
254	2000	CHRYSLER	CARAVAN	1	2		2	3	1	3	1	
255	2000	CHEVROLET	S-10	1	2		4		1	1	1	
256	2003	CHEVROLET	SUBURBAN	1	3		2	0	1	3	0	Q6; All, Q9; done buying cars
257	1998	CHRYSLER	CARAVAN	1	1	3	1	1	1	1	2	
258	2004	FORD	TAURUS	1	2		4		1	1	2	
259	2003	CHEVROLET	TAHOE	1	2		3	3	1	2	2	

Appenidx T: Complete awareness survey responses (con't)

#	YEAR	MAKE	MODEL	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Additional Comments
260	2003	CHEVROLET	YUKON	1	2		2	2	1	2	2	
261	2003	CHEVROLET	TAHOE	1	3		2	4	1	1	1	
262	1999	CHRYSLER	PLY. VOYAGER	1	2		2	1	0	0	0	Q7-9; would need more fuel info
263	2004	CHEVROLET	TAHOE	1	1	2	2	4	1	4	1	
264	2000	CHRYSLER	CARAVAN	1	2		2	2	1	4	1	
265	2003	CHEVROLET	TAHOE	1	2		2	1	1	3	2	
266	2004	CHEVROLET	TAHOE	1	2		2	2	1	4	1	
267	2003	CHEVROLET	TAHOE	1	1	2	2	0	1	1	1	Q6; lack of refining capability
268	2002	CHEVROLET	SUBURBAN	1	3		1	1	1	2	1	
269	2003	CHEVROLET	SUBURBAN	1	2		2	3	1	4	1	
270	1999	CHRYSLER	CARAVAN	1	2		2	2	1	3	1	
271	1998	CHRYSLER	CARAVAN	2	2		2	4	1	2	1	
272	2000	FORD	TAURUS	2	2		1	4	1	2	1	
273	2004	CHRYSLER	STRATUS	2	3		2	1	1	3	1	
274	1999	CHRYSLER	CARAVAN	2	2		3	1	1	1	1	
275	2004	CHEVROLET	TAHOE	2	2		1	1	1	1	1	
276	2004	CHEVROLET	YUKON	2	2		1	1	1	2	1	
277	2004	CHEVROLET	SUBURBAN	2	3		3	2	1	4	1	
278	1999	CHRYSLER	CARAVAN	2	2		1	1	1	4	1	
279	1998	CHRYSLER	CARAVAN	2	3		2	2	1	1	2	
280	2003	CHEVROLET	SUBURBAN	2	2		2	3	1	1	1	
281	2003	CHEVROLET	TAHOE	2	3		1	1	1	2	1	
282	2003	CHEVROLET	TAHOE	2	3		2	2	1	2	1	
283	2004	CHEVROLET	SUBURBAN	2	2		2	1	1	1	1	
284	2003	CHEVROLET	TAHOE	2	2		2	2	1	4	1	
285	2000	CHRYSLER	CARAVAN	2	3		2	1	1	2	1	
286	2002	CHEVROLET	TAHOE	2	2		1	1	1	1	1	
287	2002	CHEVROLET	TAHOE	2	2		1	4	0	4	1	Q7; probably
288	2002	CHEVROLET	TAHOE	2	2		2	1	1	0	1	Q8; doesn't know
289	2002	CHEVROLET	TAHOE	2	2		2	1	1	3	1	
290	2004	CHEVROLET	SUBURBAN	2	2		1	2	2		1	
291	2003	CHEVROLET	SUBURBAN	2	2		1	4	1	4	1	
292	2002	CHEVROLET	SUBURBAN	2	2		2	2	1	4	1	
293	1999	CHRYSLER	CARAVAN	2	3		2	1	1	1	1	
294	2003	CHEVROLET	TAHOE	2	2		2	4	1	3	1	
295	2004	CHEVROLET	SUBURBAN	2	2		4		1	1	1	
296	1998	CHRYSLER	PLY. VOYAGER	2	2		2	3	0	3	1	Q7; Possibly
297	2002	CHEVROLET	SUBURBAN	2	3		1	1	1	1	1	
298	2003	CHEVROLET	YUKON	3	3		1	0	1	4	1	Q6; big businesses taking advantage of the consumer
299	2003	CHEVROLET	SUBURBAN	3	2		2	3	1	3	1	
300	2004	CHEVROLET	YUKON	3	2		4		1	4	1	
301	2004	CHEVROLET	SUBURBAN	3	2		1	2	1	4	1	
302	2002	CHEVROLET	TAHOE	3	2		3	1	1	1	1	
303	2002	CHEVROLET	YUKON	3	2		4		1	1	1	
304	2003	CHEVROLET	SUBURBAN	3	2		2	1	1	2	1	
305	2000	FORD	RANGER	3	2		3	3	1	3	2	
306	2004	CHEVROLET	YUKON	3	3		1	3	1	4	1	
307	2002	CHEVROLET	YUKON	3	2		4		2		1	
308	2004	CHEVROLET	TAHOE	3	2		1	3	1	2	0	Q9; doesn't know

Appendix U: Awareness survey response summary: statistics

Private Owners	6,423	
Randomly Selected Owners	1,000	16%
Found Phone Numbers	742	74%
Positive Survey Responses	308	42%
Negative Survey Responses	87	12%
Phone number invalid	87	12%
Call backs, not reached again	53	7%
Not Reached after 2 attemps	207	28%

Question	Response	#	%	90% CI	
1.Do you still own a YEAR-MAKE-MODEL?	Yes	288	94%		
	No	20	6%		
	Total	308			
2.What fuel (grade) do you typically use?	Regular	250	87%	.+/-	4.9%
	Mid-grade	27	9%	.+/-	4.2%
	Premium	11	4%	.+/-	2.8%
	Total	288			
3.Can your vehicle run on any fuel other than gasoline?	Yes	38	13%	.+/-	4.9%
	No	184	64%	.+/-	7.0%
	Doesn't know	66	23%	.+/-	6.1%
	Total	288			
4. If yes, how much of a factor was this in deciding to purchase this vehicle?	Big	1	3%	.+/-	6.4%
	Small	9	24%	.+/-	17.0%
	Not at all	28	74%	.+/-	17.6%
	Total	38			
5. How concerned are you about the state of fuel in the US?	Very	117	38%	.+/-	9.1%
	Moderately	135	44%	.+/-	9.3%
	Somewhat	40	13%	.+/-	6.3%
	Not at all	16	5%	.+/-	4.2%
	Total	308			
6. What is your biggest concern related to fuel?	Pollution	34	12%	.+/-	6.2%
	Rising Cost	115	39%	.+/-	9.4%
	Dependance	88	30%	.+/-	8.8%
	Limited Supply	47	16%	.+/-	7.1%
	Other	8	3%	.+/-	3.1%
	Total	292			
7. If available, would you buy an alternative fuel that is made in the US from renewable resources and causes less pollution?	Yes	287	93%	.+/-	2.4%
	No	5	2%	.+/-	1.2%
	Other	16	5%	.+/-	2.1%
	Total	308			
8. How much more per gallon would you be willing to pay for that alternative fuel?	None	91	30%	.+/-	8.7%
	5 cents	55	18%	.+/-	7.3%
	10 cents	61	20%	.+/-	7.6%
	20 cents or more	86	28%	.+/-	8.5%
	Other	10	3%	.+/-	3.4%
	Total	303			
9. If performance, cost and style were similar to conventional gasoline vehicles, would you choose to buy a new vehicle that would run on an alternative fuel?	Yes	262	85%	.+/-	3.3%
	No	26	8%	.+/-	2.6%
	Other	20	6%	.+/-	2.3%
	Total	308			

Appendix U: Awareness survey response summary: 'other' responses

6. What is your biggest concern related to fuel?

Q6; Administration
Q6; All of the Above (3)
Q6; Concerned with big businesses taking advantage of the consumer
Q6; Lack of alternatives
Q6; Lack of refining capability
Q6; Larger vehicles
Q6; Not enough support for the farmers
Q6; Not enough drilling in Alaska

7. If available, would you buy an alternative fuel that is made in the US from renewable resources and causes less pollution?

Q7; Depends on many other factors
Q7; Doesn't know (3)
Q7; Doesn't know much about the vehicle
Q7; If it worked in their vehicle - they got rid of their FFV
Q7; Not ready for alternatives yet
Q7; Perhaps
Q7; Possibly (5)
Q7; Probably
Q7; Would need to know more about the fuel (3)

8. How much more per gallon would you be willing to pay more for that alternative fuel?

Q8; Can't put a price on it
Q8; Depends on fuel economy
Q8; Doesn't know (4)
Q8; Doesn't know much about the vehicle
Q8; Too hard to know
Q8; Would need to know more about the fuel

9. If performance, cost and style were similar to conventional gasoline vehicles, would you choose to buy a new vehicle that would run on an alternative fuel?

Q9; Doesn't know (5)
Q9; Doesn't know much about the vehicle
Q9; Done buying vehicles
Q9; If fuel is not more expensive
Q9; If they came in big sizes
Q9; Maybe (2)
Q9; Maybe, concerned about supply
Q9; Not ready for alternatives yet
Q9; Not sure
Q9; Perhaps
Q9; Possibly (2)
Q9; Questionable
Q9; Too many factors to consider
Q9; Would need to know more about the fuel