METHANOL AND ETHANOL

Fuel Description

Methanol. Methanol is also known as methyl alcohol and its chemical formula is CH_3OH. Commercially, methanol is most commonly produced by steam reforming of natural gas. In this process, the natural gas is first transformed into CO and hydrogen. Methanol is then produced by combining the CO and hydrogen under high temperature and pressure in the presence of special catalysts. Methanol was once made from the destructive distillation of wood (hence its other common name, "wood alcohol"), but this process is no longer economically viable. The U.S. currently produces around six million metric tons per year (two billion gallons) of methanol, about 25% of world production. Both world and U.S. production use natural gas as the primary feedstock for about 90% of production. Methanol price per gallon has varied between 30 and 80 cents/gallon since 1983, except for a large price spike in 1994 when the price reached the $1.60 per gallon range. (The price spike was due to a step-change in demand for methanol to produce MTBE[19] for reformulated gasoline that was required to be sold in 30 non-attainment areas across the country starting in 1995, and due to untimely production plant shut-downs.) Prices have since returned to traditional levels.[20]

Methanol's primary uses are as a chemical feedstock and industrial solvent. It is the fuel used at the Indianapolis 500 because it burns without producing black smoke.[21] Methanol has a lower energy density than gasoline—a gallon of methanol contains 56,600 Btus whereas a gallon of gasoline has approximately 115,400 Btus (i.e., methanol has 49% of the energy density of gasoline per gallon). However, the combustion efficiency of methanol is the same or slightly better than gasoline. Hence its volumetric fuel economy (miles per gallon) is also about half of gasoline fuel economy, causing driving range to be reduced by about half unless fuel tank capacity is increased.

Ethanol. Ethanol is also known as ethyl alcohol and its chemical formula is C_2H_5OH. Ethanol is currently made by fermenting corn, although other grains also can be used. Ethanol has long been added to gasoline as a 10% blend (in certain parts of the country) known as "gasohol." When ethanol is added to gasoline, it

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[19] Methyl tertiary butyl ether, produced from methanol and isobutylene.

[20] Grigsby, B.J., "Current Status and Outlook for the Methanol Market in the United States," 1995 World Methanol Conference, Phoenix, Arizona, December 5-7, 1995.

[21] Methanol was first introduced at the Indianapolis 500 after the very bad crash in 1963 where popular driver Eddie Sachs was killed. The consensus about that crash is that it was made much worse by the fact that the gasoline burning from wrecked cars created a large cloud of black smoke that obscured vision, which in turn caused more collisions. Methanol's advantage of burning without smoke is also one of its safety concerns—its flames are invisible in direct sunlight.

improves the octane of that gasoline and lowers emissions of CO. Like methanol, ethanol reacts with metals and elastomers but not as aggressively as methanol. A gallon of ethanol contains approximately 76,000 Btus per gallon (65% of the energy density of gasoline).

Ethanol made via fermentation is expensive, and there also is disagreement whether the energy used to produce crops and then convert them to ethanol is less than the energy content of the ethanol fuel. Much of the energy used to produce ethanol is derived from natural gas, propane, and coal, which are all domestic resources. Even if the energy balance is questionable, the net result of ethanol use in vehicles would be a reduction in petroleum imports and reduced dependence of the transportation sector on petroleum fuels.

The U.S. Department of Energy is working to develop technology to produce ethanol from cellulosic materials such as waste paper and fast growing hybrid trees.[22] The cost of ethanol produced from these sources is believed to be low enough to compete with petroleum fuels. Ethanol produced from cellulose is also believed to have significant greenhouse gas benefits.

Fuel Properties

Methanol and ethanol are both clear liquids with low volatility and faint odors. Unlike gasoline, which contains a wide assortment of hydrocarbon molecule types, both methanol and ethanol are single-molecule liquids (e.g., a tank of methanol is full of identical molecules). Table 2.14 contrasts the properties of gasoline with methanol and ethanol.

As Table 2.14 illustrates, gasoline is composed of relatively high molecular weight hydrocarbons compared to methanol and ethanol. Gasoline has a wide, continuous boiling range while methanol and ethanol have single boiling points in the middle of the gasoline boiling point range. Gasoline is much more volatile than methanol or ethanol in part due to the low-boiling-point compounds it contains. These characteristics of methanol and ethanol initially caused problems with cold-start in light-duty spark ignition engines. In fact, neat methanol (100% methanol) will not start in typical spark ignition engines at temperatures below about 45°F. This drawback was found to be easily solved by the addition of 15 volume percent gasoline, resulting in a blend referred to as M85. This amount of gasoline not only solves the cold-start problem, but makes methanol flames visible enough to allay the safety concern about flame visibility in daylight. (It is common practice to add 15 volume percent gasoline to ethanol, producing a blend called E85, for the same reasons.) In the coldest

[22] Anon., "Alternatives to Traditional Transportation Fuels 1995," U.S. Department of Energy, Energy Information Administration, internet site (http//www.doe.eia.gov), December 2, 1996.

Table 2.14 Properties of Gasoline, Methanol, and Ethanol

Fuel Property	Gasoline	Methanol	Ethanol
Molecular Weight	100 to 105	32.04	46.07
Composition, Weight % Carbon Hydrogen Oxygen	 85-88 12-15 0-4	 37.5 12.6 49.9	 44.9 12.7 42.4-43.0
Weight, lb/gallon	6.0 to 6.5	6.6	6.6
Boiling Point, °F	80-437	149	172
Reid Vapor Pressure, psi	7-15	4.6	2.3
Lower Heating Value, Btu/gallon	109,000 - 119,000	56,800	76,000
Latent Heat of Vaporization, Btu/lb	150	506	396
Solubility in Water, %	Negligible	100	100
Octane Number, (R+M)/2	87-93	99	100
Autoignition Temperature, °F	495	867	793
Flame Visibility	Visible Under All Conditions	Invisible in Daylight	Difficult to See in Daylight

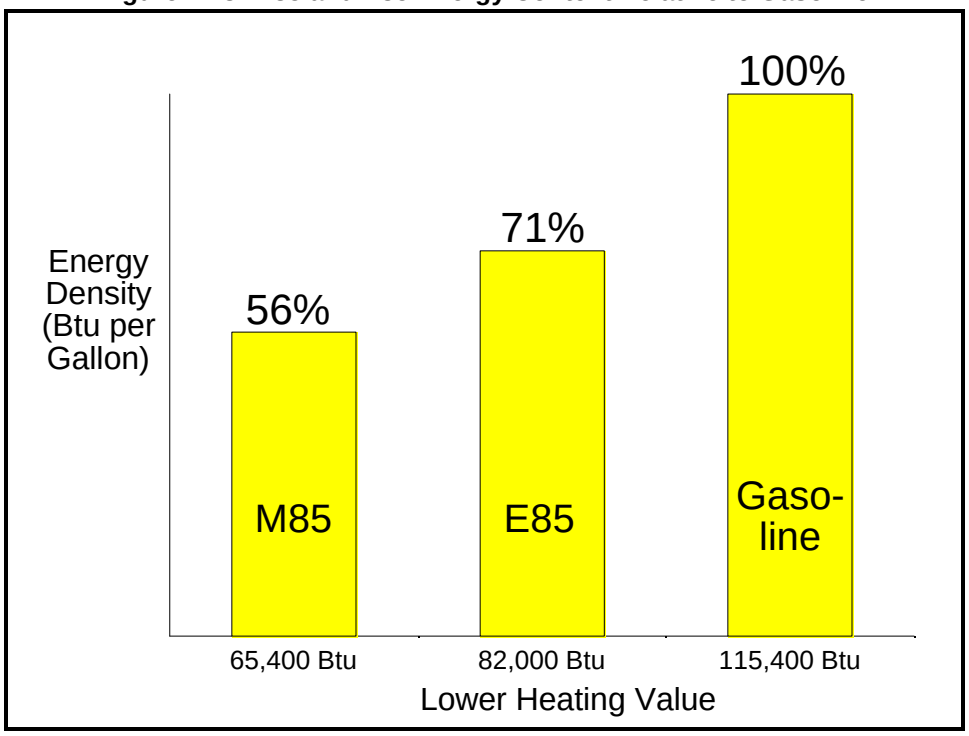
weather typical of that experienced in parts of New York State, use of M70 and E70 (i.e., 30 volume percent gasoline) may be warranted to prevent cold-start problems.

Figure 2.28 illustrates the difference in energy content among M85, E85, and gasoline. One gallon of M85 has only 56% of the energy of one gallon of gasoline, while E85 has 71%. This means that it takes 1.75 gallons of M85 to equal one gallon of gasoline, and 1.4 gallons of E85 to equal one gallon of gasoline.

Methanol is poisonous,[23] and prolonged exposure to vapors and wetting of the skin are to be avoided. Ingestion is to be strictly avoided, and the addition of 15% gasoline makes the fuel smell like gasoline, discouraging consumption. Ethanol is the alcohol contained in alcoholic beverages, and to prevent fuel-ethanol from being consumed by humans it is "denatured" by addition of 5 volume percent gasoline before leaving the production

[23] Ingesting more than a few ounces of methanol can cause blindness or death. While gasoline is not poisonous, ingestion of gasoline can cause death due to chemical pneumonia. Gasoline also includes benzene, a known carcinogen, and other suspected carcinogens.

Figure 2.28 M85 and E85 Energy Content Relative to Gasoline



plant. (Other ethanol denaturants approved for use contribute a repulsive smell, but gasoline is the least expensive and most popular denaturant.) Methanol and fuel-ethanol are more corrosive than gasoline and require that minor changes be made in gasoline fuel system materials to be compatible.

Emissions Reactivity

The exhaust products of methanol and ethanol (M85 and E85) are about 50% and 30% less reactive (respectively) than the same mass of hydrocarbons from typical conventional gasoline.[24,25] (The exhaust from reformulated gasoline is between 5 and 10% less reactive than from conventional gasoline.) Unlike dedicated CNG vehicles, vehicles using M85 or E85 will have similar evaporative and refueling emissions as gasoline vehicles. The overall ozone-forming potential of M85 and E85 used in vehicles will be similar to the difference in reactivity on a mass basis relative to conventional or reformulated gasoline.

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[24] Burns, V.R., et.al., "Emissions with Reformulated Gasoline and Methanol Blends in 1992 and 1993 Model Year Vehicles," SAE Paper No. 941969, SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001.

[25] Benson, J.D., et.al., "Emissions with E85 and Gasolines in Flexible/Variable Fuel Vehicles - The Auto/Oil Air Quality Improvement Research Program," SAE Paper No. 952508, SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001.

Greenhouse Gases

The CO_2 emissions of methanol vehicles are about 94% those of similar gasoline vehicles, assuming they have the same fuel efficiency. In the AFV-FDP, vehicles using methanol were found to use 7% less energy than when using gasoline. Combining increased fuel efficiency with the inherent combustion advantage of methanol yields CO_2 emissions that are only 87% those of gasoline vehicles. However, producing methanol releases almost half as much more greenhouse gases than producing gasoline does. When the entire fuel cycle from resource through combustion is included, methanol has very similar greenhouse gas emissions relative to gasoline.[26,27] (See Appendix F for an explanation of greenhouse gases and global warming.) The greenhouse gases from advanced methanol vehicles could be reduced by using more efficient engines or fuel cells.

Ethanol vehicles' CO_2 emissions are about 97% those of similar gasoline vehicles with the same fuel efficiency. However, for ethanol produced from corn (currently the feedstock used most), all the CO_2 produced from combustion in the vehicle is from carbon in the corn. This carbon came from atmospheric CO_2 absorbed by the corn plants for growth. Using ethanol in vehicles thus creates only a small increase in greenhouse gas emissions, from vehicle emissions other than CO_2. However, production of corn from which ethanol is made creates almost three times the greenhouse gas emissions that refining crude oil to gasoline does. Overall, the full fuel cycle greenhouse gas emissions for ethanol produced from corn are similar to those of gasoline from crude oil.[28]

The U.S. Department of Energy is working on technologies to produce ethanol from cellulosic materials such as waste paper and fast-growing hybrid trees.[29] The cost of ethanol produced from these sources might be low enough to compete with petroleum fuels. Ethanol produced from cellulose is also believed to produce full fuel cycle greenhouse gases that are only about 60% those of gasoline from crude oil.

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[26] "Alternatives to Traditional Transportation Fuels - 1994 - Volume 2: Greenhouse Gas Emissions," U.S. Department of Energy, Energy Information Administration, Report No. DOE/EIA-0585(94)/1, February 1996.

[27] Wang, M.Q., "Development and Use of the GREET Model to Estimate Fuel-Cycle Energy Use and Emissions of Various Transportation Technologies and Fuels," Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439, March 1996.

[28] "Alternatives to Traditional Transportation Fuels - 1994 - Volume 2: Greenhouse Gas Emissions," U.S. Department of Energy, Energy Information Administration, Report No. DOE/EIA-0585(94)/1, February 1996.

[29] The U.S. Department of Energy Biofuels Feedstock Development Program, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN, 37831-6422.

Vehicle Technology

Table 2.15 lists the methanol and ethanol vehicles that were included in the AFV-FDP. All these vehicles are "flexible fuel vehicles" or FFVs. FFVs have a sensor that is able to measure the amount of alcohol in the fuel going to the engine. FFV sensor technology represented a large step forward to commercialization of alcohol vehicles because it freed the vehicle from having to rely on using only alcohol fuel that was sure to be in limited supply geographically. FFVs use gasoline or alcohol (whichever is available) in the same fuel tank. No interaction is required by the driver when changing fuels—the driver just puts fuel in the tank and the engine

Table 2.15 Light-Duty FFVs Active in the AFV-FDP Fleets

Fleet	Vehicle Make and Model	Number of Vehicles	Fuel Type	Engine	Fuel Tank Size (gal)
NYS Thruway Authority	1986 Ford Crown Victoria FFV	4	M85/Gasoline	5.0L V-8	18.0
NYS Thruway Authority & NYSERDA	1989 Ford Crown Victoria FFV	14	M85/Gasoline	5.0L V-8	18.0
Monroe County	1991 Ford Taurus FFV	5	M85/Gasoline	3.0L V-6	18.6
NYS Thruway Authority	1993 Ford Taurus FFV	40	M85/Gasoline	3.0L V-6	16.0
City of White Plains	1989 Ford Crown Victoria FFV Station Wagon	1	M85/Gasoline	5.0L V-8	18.0
City of White Plains	1991 Volkswagen Jetta FFV	1	M100	1.8L I-4	14.5
City of White Plains	1992 Volkswagen Jetta FFV	1	E85	1.8L I-4	14.5

control system makes all the changes necessary. The drawback to FFVs is that they cannot be optimized for both gasoline and alcohol. To date, FFVs have been calibrated so that operation using gasoline is very similar to operating on alcohol. FFVs could be calibrated for better operation using alcohol, but operation on gasoline would then be inferior, which is not believed to be desirable by users who will have to switch between the two fuels. Many vehicle manufacturers have built and experimented with FFVs including Ford, General Motors, Chrysler, Toyota, Honda, Nissan, Mitsubishi, Volvo, Volkswagen, Porsche, and Mercedes Benz. Of these manufacturers, only Ford, General Motors, and Chrysler have sold FFVs in the U.S. (The Volkswagen FFVs used in this project are experimental vehicles not for sale to the public.)

Figure 2.29 White Plains 1989 Ford Crown Victoria Flexible Fuel Vehicle

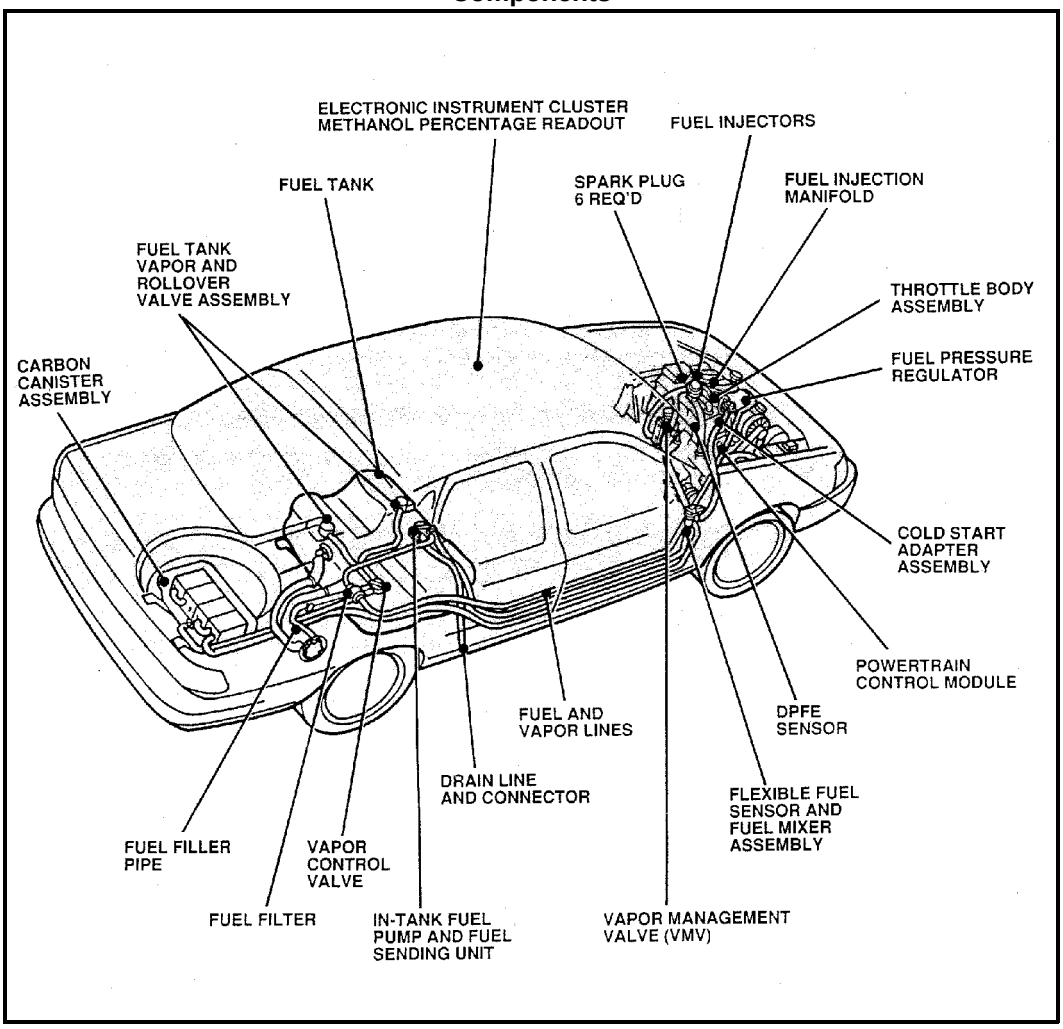
The Ford Crown Victoria FFVs were among the first generation of FFVs built. The 1986 models were used by the New York State Thruway to the end of their useful lives, and the experience has been documented by NYSERDA.[30,31] The 1989 model Crown Victoria FFVs are no longer active as FFVs in the AFV-FDP program, having been reconverted by Ford to gasoline-only operation in 1994 and 1995 (see Figure 2.29). The prime vehicle experience with NYSERDA took place with the production 1993 Ford Taurus vehicles (see Figure 2.30). These were the third generation of Ford FFVs and, though the design has been further upgraded in the 1996 Ford Taurus FFV, these vehicles continue in operation with the Thruway Authority.

Figure 2.30 Thruway Authority 1993 Ford Taurus Flexible Fuel Vehicle

[30] Bechtold, R.L., M.T. Miller, and J.D. Hyde, "Ford Methanol FFV Performance/Emissions Experience," SAE Paper No. 902157, SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001.

[31] "Methanol Fuel Vehicle Demonstration: Exhaust Emission Testing," NYSERDA Report 93-10, July 1993.

Figure 2.31 Schematic of Ford Taurus Flexible Fuel Vehicle Identifying Modified Components



As stated in the Taurus FFV Training Reference Book, "The 3.0L FF Taurus fuel delivery and control, evaporative emission and ignition systems function similar to the unleaded gasoline systems. However, some major changes are required to handle methanol fuel. These changes include the components to be made with materials that are compatible with methanol fuel (see Figure 2.31). Some of these components are identical and perform the same functions as on unleaded gasoline vehicles."[32] Components that are unique (or specialized) for the FFVs include:

- Powertrain Control Module - The powertrain control module (PCM) maintains a prescribed air-fuel ratio throughout the entire engine operation range. The calibration for flexible fuel is unique. Using inputs from the flexible fuel sensor and various engine sensors, the PCM outpits a command to the cold start injector and engine fuel injector to meter the proper quantity of fuel.

[32] 1993 Flexible Fueled Vehicles, New Model Training Reference Book, 3.0L Taurus, Ford Parts and Service Division, Technical Training, 1992.

Figure 2.32 Ford Taurus FFV Cold Start Injector Assembly

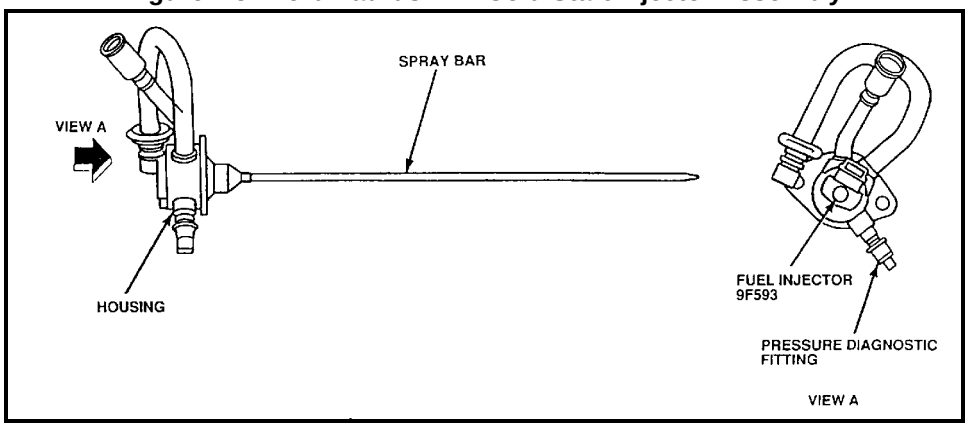
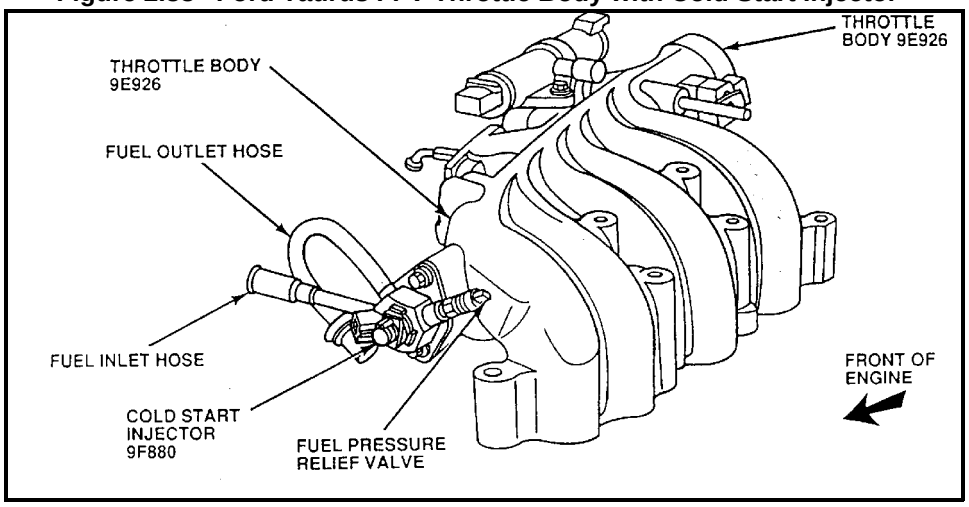


Figure 2.33 Ford Taurus FFV Throttle Body with Cold Start Injector



- Cold Start Adapter Assembly - The cold start injector (CSI) provides additional fuel to improve cold weather starts. (Figure 2.32 shows the CSI assembly and Figure 2.33 shows the CSI assembly mounted in the throttle body of the intake manifold.)

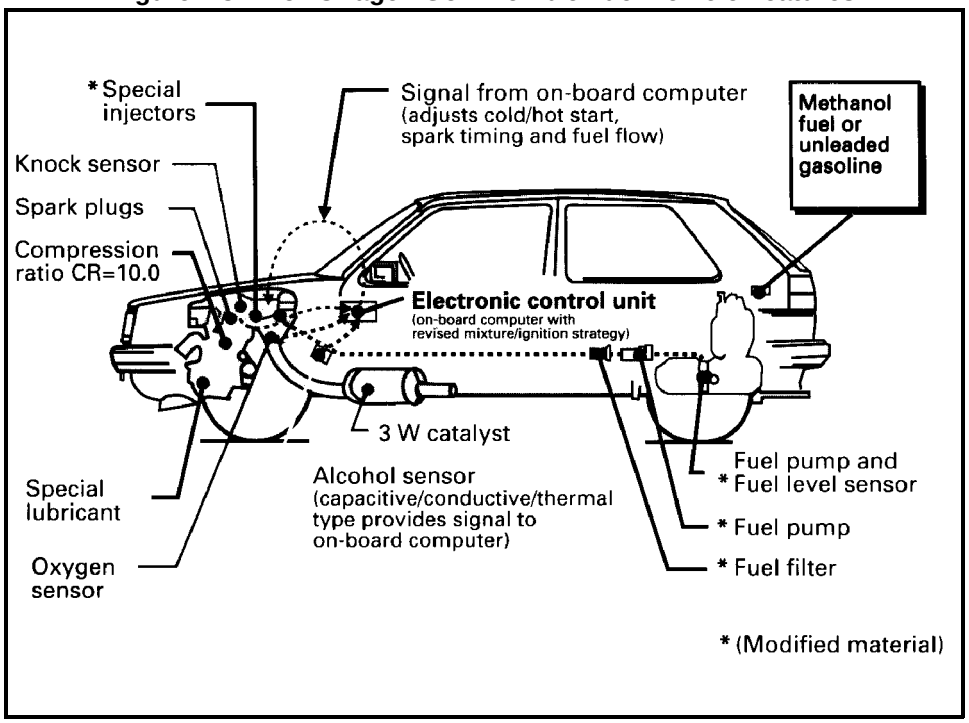
- Flexible Fuel Sensor - The flexible fuel sensor detects the percentage of methanol in the fuel blend and relates this information to the fuel control module.

- Fuel Injectors - The fuel injectors deliver fuel to the engine. The flexible fuel injectors have a higher flow rate than fuel injectors in unleaded gasoline vehicles to compensate for the lower heat content per volume of methanol blend fuel.

- Fuel Tank - The fuel tank stores the fuel blend. The fuel tank is constructed of high density polyethylene for protection against corrosion.

The Volkswagen Jetta FFV engine was developed using experience gained by Volkswagen in Brazil, where ethanol made from sugar cane is used as a vehicle fuel. The fuel system has the same functional components and engine changes as described for the Ford Taurus. Figure 2.34 displays the layout of the components on a Volkswagen Golf, which is the same model as the Jetta sedan except that the Golf is a hatchback.

Figure 2.34 Volkswagen Golf Flexible Fuel Vehicle Features



Both Ford Motor Company and Volkswagen require oil that is specially formulated for use in their flexible fuel vehicles.

The majority of the operating experience in the AFV-FDP was gained from the 40 1993 Ford Taurus FFVs, which were leased by Ford to the New York State Thruway Authority. Five 1991 Ford Taurus FFVs were sold as experimental units and operated by Monroe County. The two Volkswagens were used by the City of White Plains. The Thruway FFVs were subjected primarily to highway driving conditions. The Monroe County and While Plains FFVs were operated primarily in urban traffic conditions.

Refueling Infrastructure

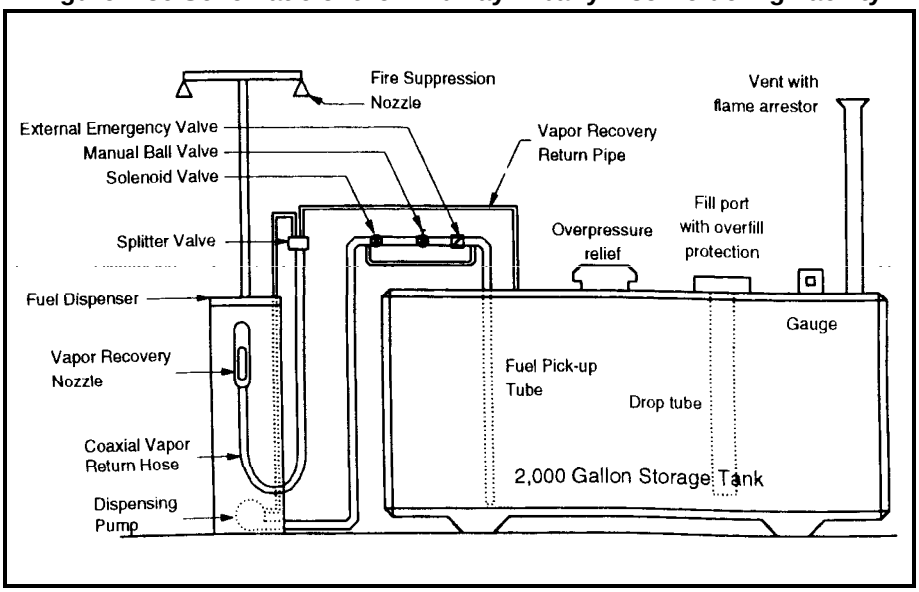
Refueling Facilities. Similar aboveground fuel tanks, dispensers, and fire suppression systems were installed at all the AFV-FDP sites using M85 or E85 fuel. The aboveground tanks were welded steel tanks enclosed in concrete in either 1,000- or 2,000-gallon sizes. The primary benefits of aboveground fuel storage tanks are their low cost, speed and ease of installation and relocation, and low risk of fuel leakage.

The Monroe County fleet vehicles were operated out of the maintenance facility located in Rochester. The M85 refueling station was located onsite and consisted of a 1,000-gallon aboveground storage tank and dispenser. The storage tanks and the M85 dispenser were configured for Stage II vapor recovery. The methanol compatible dispenser was supplied by Gasboy, Inc. Emco Wheaton supplied methanol-compatible dispensing nozzles and Goodyear methanol-compatible dispensing hose was used. The fire suppression system for the refueling facility used a dry powder and provided both overhead and curb level fire protection. Figure 2.35 illustrates this M85 refueling facility.

Figure 2.35 Monroe County M85 Refueling Facility

The Thruway Authority methanol refueling facilities were constructed at nine locations along the Thruway and include 2,000-gallon aboveground tanks (except for Westfield, which had a 1,000-gallon tank). Both Stage I and Stage II vapor recovery systems as well as fire suppression systems similar to the one at Monroe County were incorporated. The cost of each 2,000-gallon M85 aboveground storage and dispensing system including installation was about $23,000. A schematic layout of the first refueling facility constructed for Thruway

Figure 2.36 Schematic of the Thruway Albany M85 Refueling Facility



Authority use in Albany is shown in Figure 2.36. Subsequent installations moved the dispenser onto the tank which simplified the system, similar to the one installed at Monroe County (see Figure 2.35).

The methanol compatible ancillary equipment included: a fill limiter (to prevent overfilling of the storage tank); fuel dispenser with metering and vapor recovery systems; dispenser supply piping and associated control valves; tank vent stack with flame arrestor; and a fill drop tube to limit vapor generation when filling the tank. Much of the piping and ancillary equipment was installed by the tank manufacturer, which limited onsite installation work to placing the tank on a concrete pad and providing electric supply.

Nine methanol refueling systems were installed along the New York State Thruway to support the methanol FFVs operated by the Thruway Authority. Two systems were installed at the City of White Plains and one was located on Monroe County property in Rochester. Figure 2.37 gives the location of the stations. (The Monroe County station is currently inactive because M85 vehicles are no longer being used there.)

Safety was a primary design requirement of the M85 and E85 refueling facilities. Each system employed a dry powder fire suppression system (the same design and chemical used for gasoline facilities). Figure 2.38 illustrates a test of one of the fire suppression systems to ensure that the dry powder is discharged in the proper locations.

Figure 2.37 M85 Refueling Station Locations

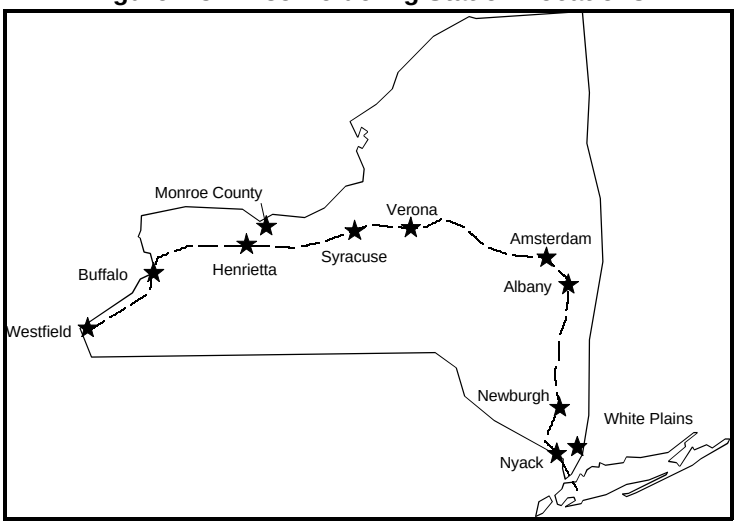


Figure 2.38 Fire Suppression Coverage Test

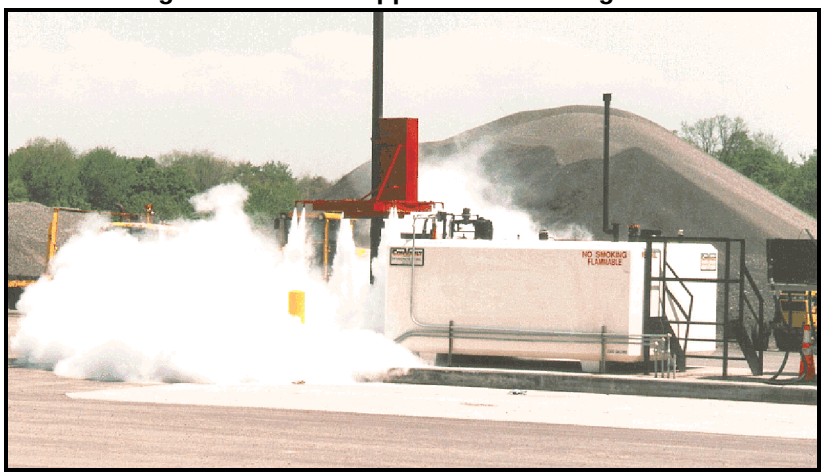


Table 2.16 lists the problems that were encountered with the alcohol fuel systems during the AFV-FDP. Most of these problems were related to materials compatibility of components with M85. None of the problems resulted in any fires, injuries, or property damage. Figure 2.39 shows the outer fuel dispensing hose that failed at the Buffalo M85 refueling facility. The outer hose just carries vapor during refueling (directing it back into the tank to avoid refueling emissions), and it was not possible to determine whether this deterioration was caused by methanol inside the hose or something from outside the hose. This failure did not result in any fuel spillage—only vapor emissions during refueling. None of the other M85 dispensing hoses failed in this manner suggesting this failure was atypical.

Table 2.16 Methanol Refueling Equipment Problems

Site	Problem	Analysis	Response	Outcome
Nyack, Newburgh, Henrietta, and Buffalo	loss of pump prime caused by rupture of Tolkeim 52-valve diaphragm	diaphragm was not compatible with methanol	valves were replaced with ones having compatible diaphragms	Tolkeim redesigned the 52-valve diaphragm
Syracuse	refueling nozzle auto stop feature did not actuate	elastomer failure in the nozzle	replaced fuel nozzle	no further problems
Buffalo	refueling nozzle would leak fuel when not in use	elastomer failure in the nozzle	replaced fuel nozzle	no further problems
Buffalo	outer portion of refueling hose developed holes allowing vapor leaks	deterioration of the outer hose material from unknown substance	replaced fuel hose	no further problems
White Plains	leak within dispenser	dissolved shaft seal in fuel pump	replaced pump seal	no further problems

Figure 2.39 Failed Dispensing Hose

These M85 fuel systems are compatible with conventional fuels which gives them value beyond the AFV-FDP. With suitable cleaning in-between, these fuel systems can be used for M85, E85, or gasoline.

Fuel Quality. Samples of the M85 used by the Thruway Authority and Monroe County FFVs were taken from each batch of fuel delivered and used. Table 2.17 presents the average values of Reid Vapor Pressure (RVP), total chloride, and water concentrations of the M85 samples. The M85 RVP varied between summer and winter according to the gasoline available for addition (all the M85 was produced by "splash" blending gasoline with neat methanol). During the summer, the RVP of the M85 used in the Thruway FFVs ranged from 7.4 psi to 8.8 psi. In the winter, the RVP ranged from 7.7 psi (a possible outlier) to 13.9 psi. For the Monroe County FFVs, the summer M85 RVP ranged from 7.5 psi to 9.8 psi, and the winter RVP ranged from 8.5 psi to 11.8 psi.

Table 2.17 Average M85 Fuel Properties

Fleet	Fuel Property	Value	No. of Samples
New York State Thruway Authority	RVP, Summer	7.9 psi	11
	RVP, Winter	11.0 psi	9
	Total Chloride	5.6 ppm	18
	Water	608 ppm	23
Monroe County	RVP, Summer	8.4 psi	6
	RVP, Winter	9.8 psi	8
	Total Chloride	5.8 ppm	11
	Water	934 ppm	11

Total chloride averaged 5.6 ppm for the Thruway Authority M85 and 5.8 ppm for the Monroe County M85. Typically, the chloride content of the M85 was less than 10 ppm. One batch of M85 delivered to Monroe County had a total chloride content of 78 ppm (average of two analyses). The source of the chloride contamination was determined to be the delivery truck since the neat methanol used to prepare the fuel had a total chloride content of 4 ppm. The high chloride M85 was properly disposed of and no subsequent batches of M85 had abnormally high chloride levels.

Chloride contamination will cause corrosion in the engine through multiple means. Methanol contaminated with chlorine has been observed to cause very rapid and severe cylinder bore wear, presumably through the

formation of hydrochloric acid.[33] Methanol contaminated with chloride ions has been demonstrated to cause rapid and severe corrosion of fuel system components such as fuel rails and fuel pumps.[34]

The average water content of the M85 used by the Thruway FFVs was 608 ppm; the Monroe County M85 averaged 934 ppm. The water content ranged from a low of about 100 ppm and a high of about 2,600 ppm.

The M85 used by the Thruway Authority and Monroe County FFVs did not cause any reliability or durability problems during the course of the demonstration. As M85 is distributed in larger quantities on a regular basis, incidents of contamination with chlorides are likely to decline.

Operations and Maintenance

Table 2.18 gives the mileage accumulation and fuel usage data for all FFVs and control vehicles. The demonstration period for which data were collected for individual fleets is also shown. Fuel dispensing at the refueling site was monitored using a card-reading system. It identified the vehicle and the driver, and also prompted for the odometer reading to be entered before refueling began. The automation of the data collection process helped to obtain reliable refueling data.

The FFVs operated through extreme weather conditions with no major failures of the fuel systems or vehicles. The 1986 and 1989 Ford Crown Victoria FFVs started operation in February 1988, and April 1991, respectively. Five 1991 Ford Taurus FFVs went into operation in Monroe County in September 1992, and were operated until October 1994. M85 usage was 66% of the total fuel consumption for the FFVs, in gallons. The vehicles operated primarily in suburban/light-urban traffic conditions. The 1993 Ford Taurus FFVs began operation in the Thruway Authority fleet in July 1993, following the completion of some of the refueling facilities along the New York State Thruway. The vehicles were operated along the Thruway under primarily highway driving conditions.

The fuel consumption of all the alcohol test and control vehicles over the duration of the AFV-FDP is illustrated in Figure 2.40. Overall, the FFVs used 47% M85, on a volume basis. The amount of alcohol used might have been higher except that not all the refueling facilities were in place when the vehicles were first delivered, and Ford specifically requested that some of their Tauruses being operated at the Thruway switch

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[33] King, E.T. and G.K. Chui, "Hardware Effects on the Wear of Methanol Fueled Engines," paper presented at the VI International Symposium on Alcohol Fuels Technology, Ottawa, Canada, May 21-25, 1984.

[34] Brinkman, N.D., R. Halsall, S.W. Jorgensen, and J.E. Kirwan, "General Motors Specifications for Fuel Methanol and Ethanol," paper presented at the Tenth International Symposium on Alcohol Fuels, Colorado Springs, Colorado, November 7-19, 1993.

back and forth between gasoline and M85. The miles traveled by the test and control vehicles is illustrated in Figure 2.41. Between 2.8 and 2.9 million miles were traveled by the test and control vehicles during the AFV-FDP.

Table 2.18 FFV Mileage Accumulation and Fuel Usage

Demonstration Vehicle	No. of Vehicles	Data Period	Cumulative Mileage	Alcohol Fuel Usage	Gasoline Usage
1986 Ford Crown Victoria	4 - FFV (NYS Thruway Authority)	2/88 - 1-92	432,000 km (270,000 miles)	20,550 l M85 (5,430 gal)	40,700 l (10,750 gal)
1989 Ford Crown Victoria	14 - FFV (NYSERDA & NYS Thruway Authority)	4/91 - 3-94	547,000 km (340,000 miles)	35,900 l M85 (9,475 gal)	59,300 l (15,675 gal)
1991 Ford Taurus	5 - FFV (Monroe County)	9/92 - 10/94	192,000 km (120,000 miles)	20,000 l M85 (5,300 gal)	10,200 l (2,700 gal)
	3 - Gasoline Control		96,000 km (60,000 miles)	-	10,600 l (2,800 gal)
1993 Ford Taurus	40 - FFV (NYS Thruway Authority)	7/93 - 12/95	3,792,000 km (2,370,000 miles)	212,000 l M85 (56,000 gal)	250,000 l (66,000 gal)
	5 - Gasoline Control		416,000 km (260,000 miles)	-	42,600 l (11,250 gal)
1991 Volkswagen Jetta	1-FFV	3/93 - 8/95	8,600 km (5,300 miles)	249 l M100 (66 gal)	942 l (249 gal)
1992 Volkswagen Jetta	1 - FFV	3/93 - 8/95	7,000 km (4,400 miles)	596 l E85 (157 gal)	293 l (77 gal)
1989 Ford Crown Victoria	1 - FFV	3/93 - 8/95	9,200 km (5,700 miles)	2,061 l M100 (544 gal)	919 l (243 gal)

Fuel Economy. Fuel economy was measured both from on-road operation and from the emissions tests conducted. Because these vehicles could and did use gasoline and alcohol fuels interchangeably, calculating on-road fuel economy for both types of fuel was not straightforward. On-road vehicle fuel economy for each type of fuel was calculated from intervals where only one fuel was used. Using this approach gives a good

Figure 2.40 FFV and Gasoline Control Vehicle Fuel Consumption

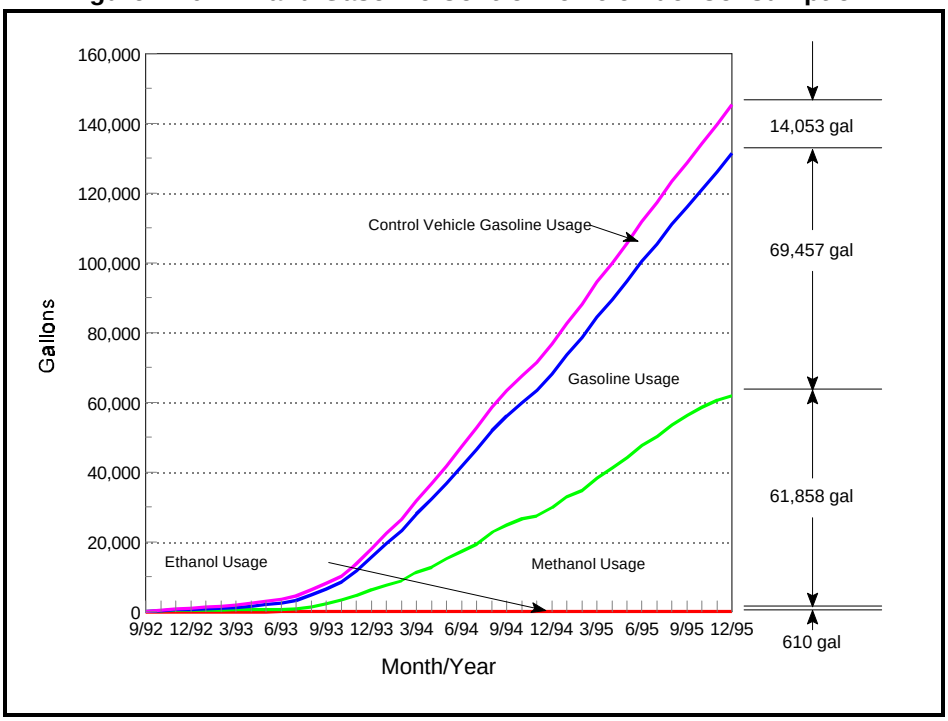
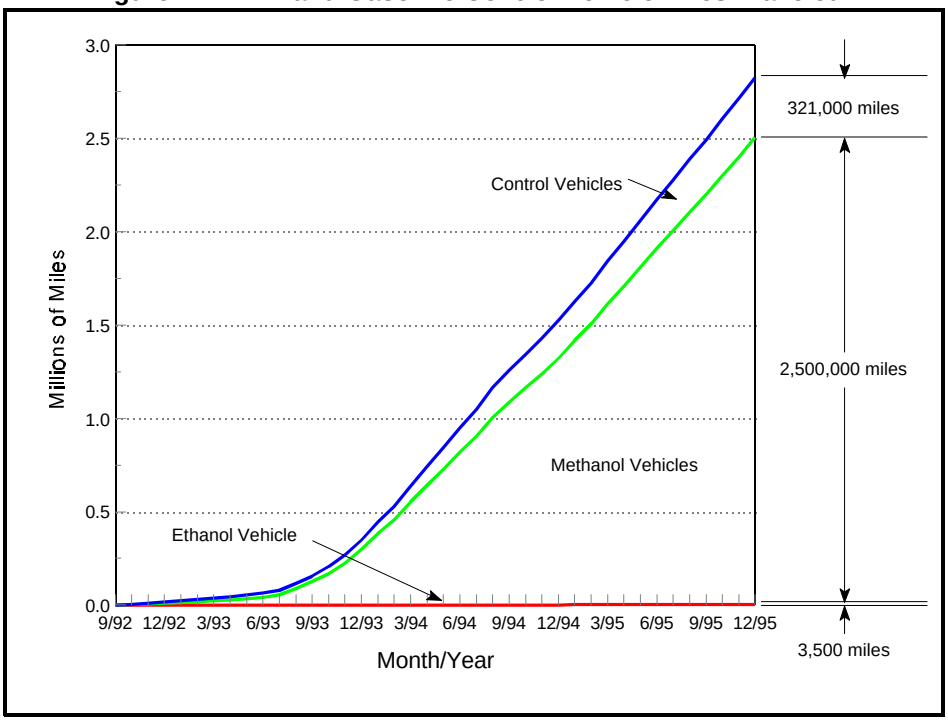


Figure 2.41 FFV and Gasoline Control Vehicle Miles Traveled



indication of the fuel economy of the vehicle in-use, but in-use fuel economy calculations tend to have significant variability because of changes in use, temperature, weather, etc. The fuel economies calculated from emissions testing are less representative of actual in-use fuel economy, but comparisons between fuels are more accurate since fuel economy variability from these controlled tests is much smaller than from in-use fuel economy.

Table 2.19 lists the fuel economies of the alcohol vehicles in the AFV-FDP. Fuel economy is expressed in both volumetric and energy equivalent terms because both methanol and ethanol have lower energy per gallon than gasoline. (Energy equivalent is the same amount of energy as in a gallon of gasoline.) It takes about 1.75 gallons of M85 and 1.40 gallons of E85 to equal one gallon of gasoline.

As shown in Table 2.19, the M85 Taurus had the highest energy efficiency both in laboratory and on-road testing, exceeding the levels measured on the baseline gasoline vehicles. Also shown in Table 2.19 is the actual volumetric gallon fuel economy. Relative to a conventional gasoline vehicle, a methanol vehicle needs a substantially larger (57% larger) methanol-compatible fuel tank to have the same range. Comparison tests from the other fleets were generally consistent with these results. The ability for the methanol fuels to deliver slightly higher energy efficiency is due to their more favorable characteristics for spark ignition engines relative to gasoline.

The fuel economy of the Thruway Authority, Monroe County, and White Plains alcohol vehicles is illustrated in Figure 2.42, Figure 2.43, and Figure 2.44, respectively.

Reliability and Durability. The four 1986 Ford Crown Victoria FFVs had several updates to their computer chips and fuel sensors. Among the components that were replaced on the vehicles were fuel sensors (four times), oxygen sensors (three times), and once each the catalytic converter assembly and the fuel pump. (The catalytic converter failure was caused by one of the fuel sensor failures.) Over the course of the Monroe County fleet operation there were four failures of the 1991 model year FFV Ford Taurus methanol fuel pump module and two failures of the fuel sensors. Replacement components were installed by Ford for each of these failures. The 1993 model year Taurus FFVs operated by the Thruway Authority did not have abnormal fuel pump or fuel sensor failures during the AFV-FDP. The Taurus FFVs operated by the Thruway Authority did not have any abnormal maintenance problems in any portion of vehicle operations.

Table 2.19 FFV and Gasoline Control Vehicle Fuel Economy

Vehicle			Highway**	City**	NYCC**	On-Road
Vehicle	Fuel	Units				
Thruway Ford Taurus FFVs	M85	miles/gal. volumetric	20.3	12.6	6.6	13.9
		miles/gal. energy equivalent*	35.8	22.3	11.6	24.4
	Gasoline	miles/gal. volumetric	35.4	21.7	11.1	22.4
Monroe County Ford Taurus FFVs	M85	miles/gal. volumetric	20.3	12.4	6.3	13.4
		miles/gal. energy equivalent*	35.8	21.9	11.2	23.7
	Gasoline	miles/gal. volumetric	33.0	19.5	10.0	22.5
	Gasoline Control	miles/gal. volumetric	34.4	21.0	10.9	22.2
White Plains Ethanol Jetta	Ethanol	miles/gal. volumetric	25.3	19.0	10.8	14.1
		miles/gal. energy equivalent*	35.8	26.9	15.2	19.9
	Gasoline	miles/gal. volumetric	33.6	24.9	13.6	15.0
White Plains Methanol Jetta	Methanol	miles/gal. volumetric	Not tested	14.2 (M85) 13.0 (M100)	8.0 (M85) 7.3 (M100)	8.4 (M75)
		miles/gal. energy equivalent*	Not tested	25.0 (M85) 26.5 (M100)	14.2 (M85) 14.9 (M100)	13.6 (M75)
	Gasoline	miles/gal. volumetric	33.1	24.9	13.67	15.1
White Plains Methanol Crown Victoria	Methanol	miles/gal. volumetric	Not tested	10.4 (M85)	Not tested	6.5 (M87)
		miles/gal. energy equivalent*	Not tested	18.4 (M85)	Not tested	11.5 (M87)
	Gasoline	miles/gal. volumetric	28.1	18.6	9.4	12.0

* Miles per Gasoline Equivalent Gallon Based on Estimated Alcohol Concentration
** EPA Highway, EPA City, and NYCC Driving Cycles are Defined in Glossary

Figure 2.42 Thruway Authority Taurus FFV Fuel Economy
(Note: Bars represent data range; lines represent averages)

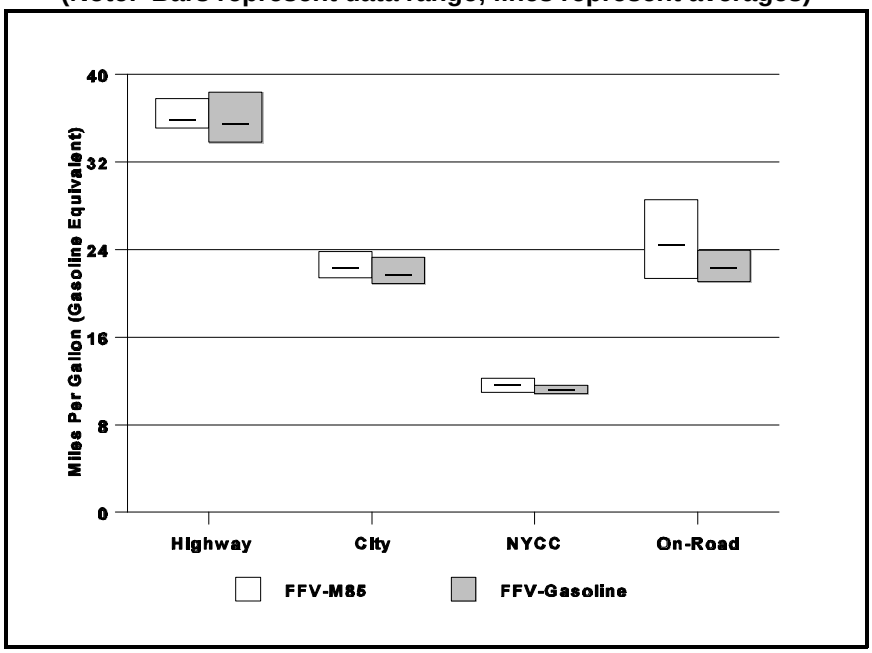


Figure 2.43 Monroe County FFV and Control Vehicle Fuel Economy
(Note: Bars represent data range; lines represent averages)

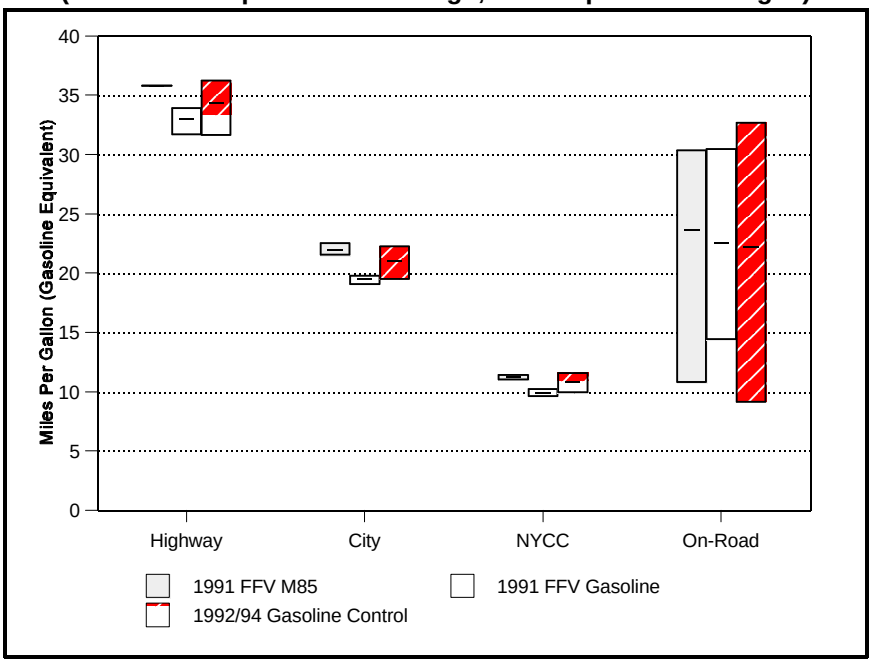
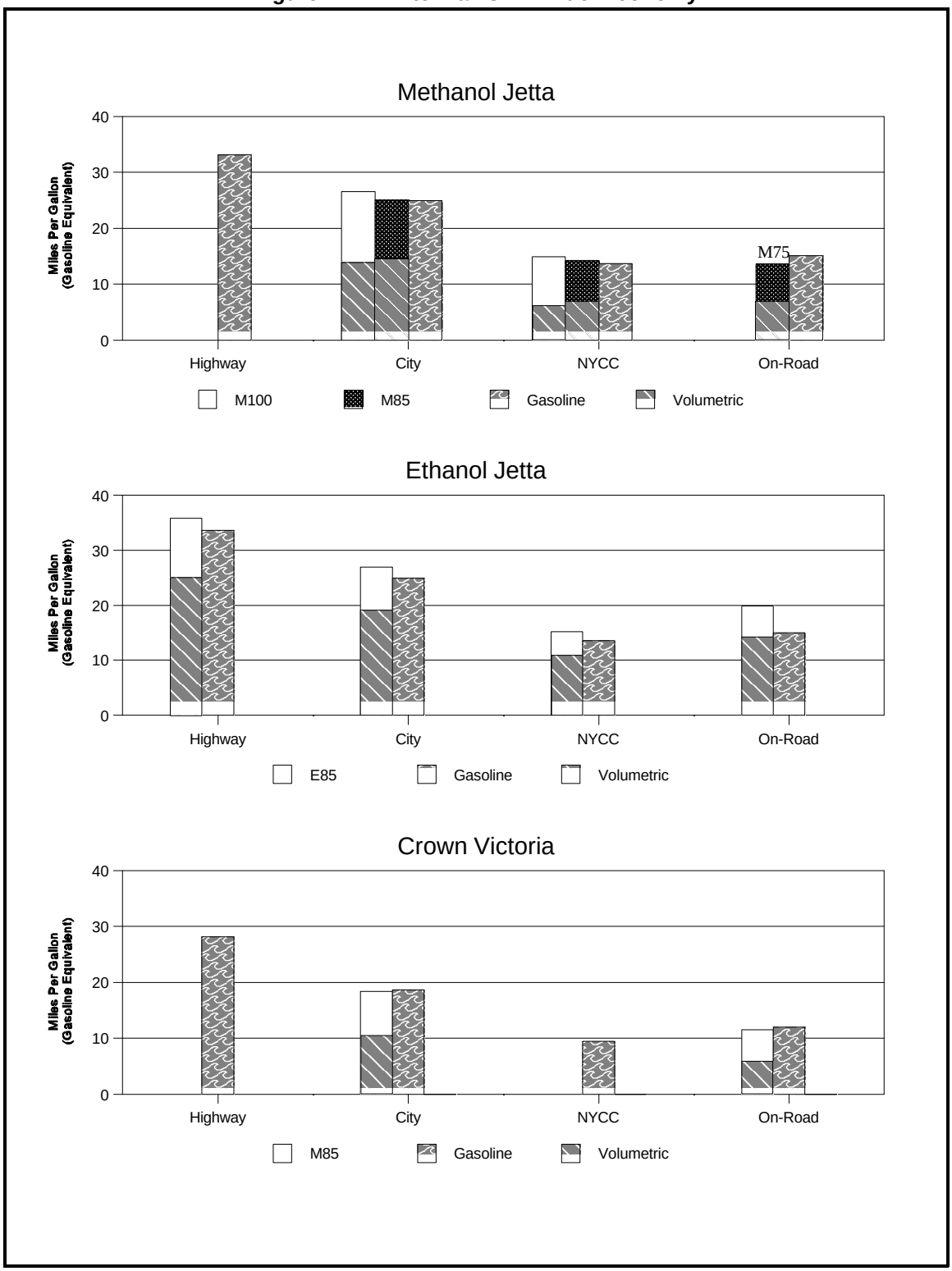


Figure 2.44 White Plains FFV Fuel Economy



Engine wear was tracked by used oil analysis from four 1993 Ford Taurus FFVs and four 1993 FFV Ford Taurus gasoline control vehicles. All the FFVs were scheduled for 3,000-mile oil change intervals, though sometimes they were driven further between oil changes. Results showing iron, aluminum, and silicon content with mileage accumulation are shown in the accompanying graphs.

Figure 2.45 Taurus FFV Used Oil Iron Content
(Note: Bars represent data range; lines represent averages)

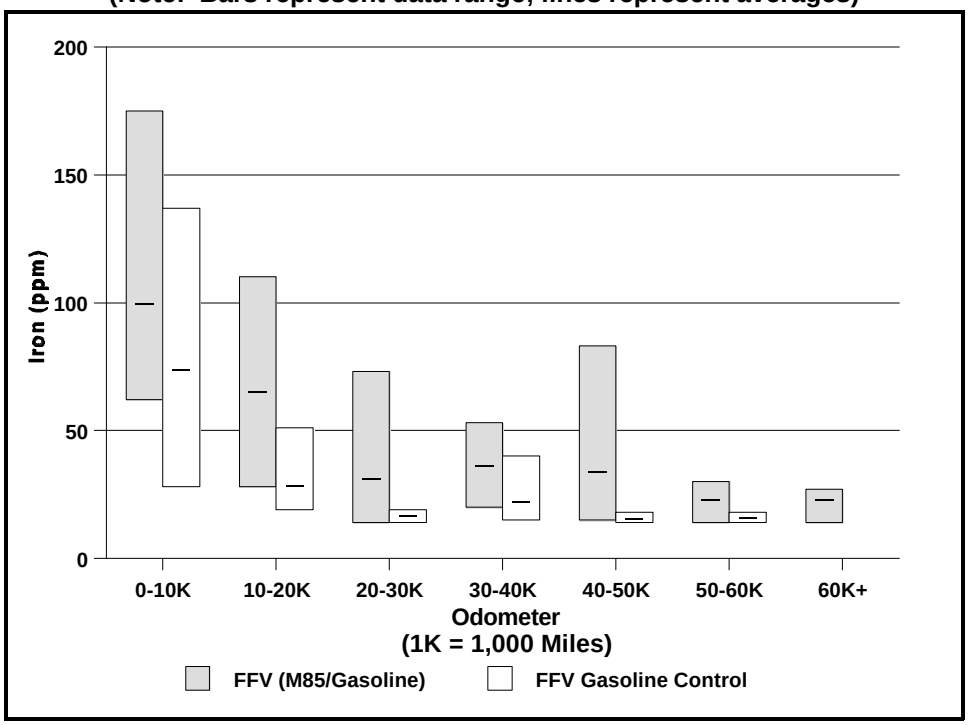
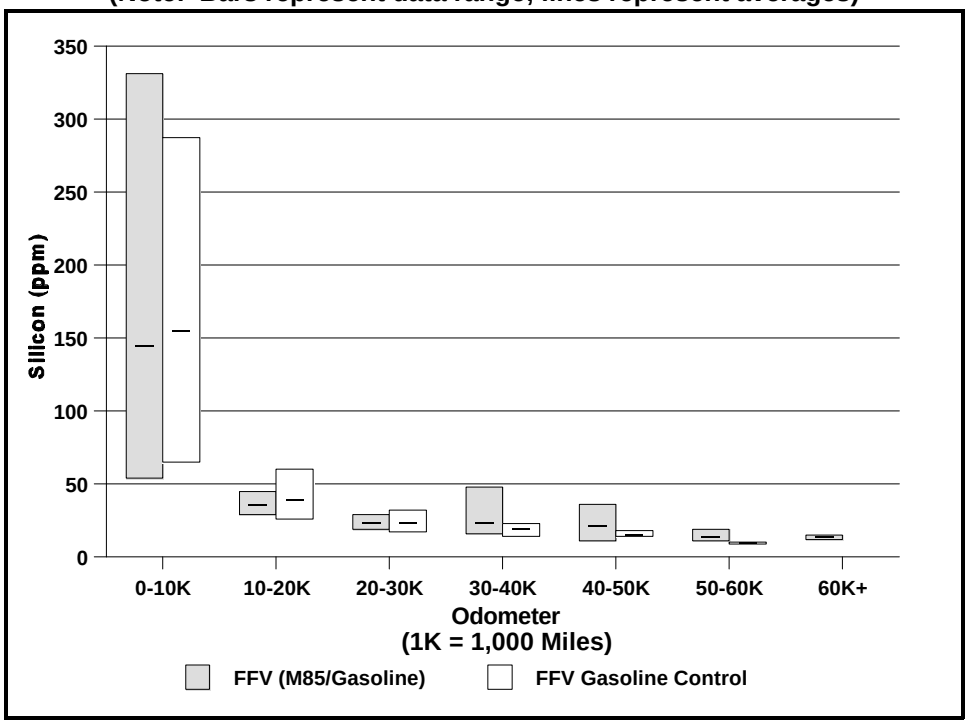


Figure 2.45 shows the iron wear metal concentration in parts per million (ppm). The graph shows an expected trend in iron wear. During the initial break-in period of the engine (0-10,000 miles) iron wear is high for both the M85 and gasoline FFVs. As the FFVs accumulate mileage, the iron content in the oil decreased for both fuels as expected. But on average iron content using M85 is higher than when using gasoline. The probable cause for this may be because of M85 washing off the thin lubricating film at the top of the cylinder, thereby resulting in higher wear rates.

Figure 2.46 shows the silicon content in used oil with mileage. Silicon content is a measure of the amount of airborne dust and dirt contamination of the engine oil. For some unknown reason, silicon content was initially high, but quickly dropped to what are considered normal levels. Both the FFVs using M85 and those using gasoline were affected similarly.

Figure 2.46 Taurus FFV Used Oil Silicon Content
(Note: Bars represent data range; lines represent averages)



Aluminum wear, shown in Figure 2.47, follows a different pattern than that seen for iron. Since fewer engine components are made from aluminum, its wear rate is significantly lower than that seen with iron. Most aluminum wear is caused by the lower portion of the piston rubbing against the cylinder walls. This contact is light and hence the wear is minimal. After an initial break-in period a small decrease is seen in aluminum wear for FFVs using M85 and a slightly greater decrease for FFVs using gasoline. Wear is higher for FFVs using M85, probably due to washing of the lubrication film by M85 or direct corrosion of the aluminum surfaces by M85. Overall, the wear metal content of the lubricating oil showed that when using M85, wear was increased slightly. However, the levels of increase are small enough that it does not present any concern about the long-term life of engines using M85 relative to using gasoline.

Acceleration. The alcohol vehicles were tested for acceleration performance by conducting wide-open-throttle acceleration runs from a standing start. Figure 2.48 illustrates the velocity vs. time relationship for the one of the Taurus FFVs operating on M85 and gasoline. Each line represents the average of three test runs. This vehicle operating on M85 had slightly faster 0-60 mph acceleration times (11.6 secs) than when operated on gasoline (11.8 secs).

Figure 2.47 Taurus FFV Used Oil Aluminum Content
(Note: Bars represent data range; lines represent averages)

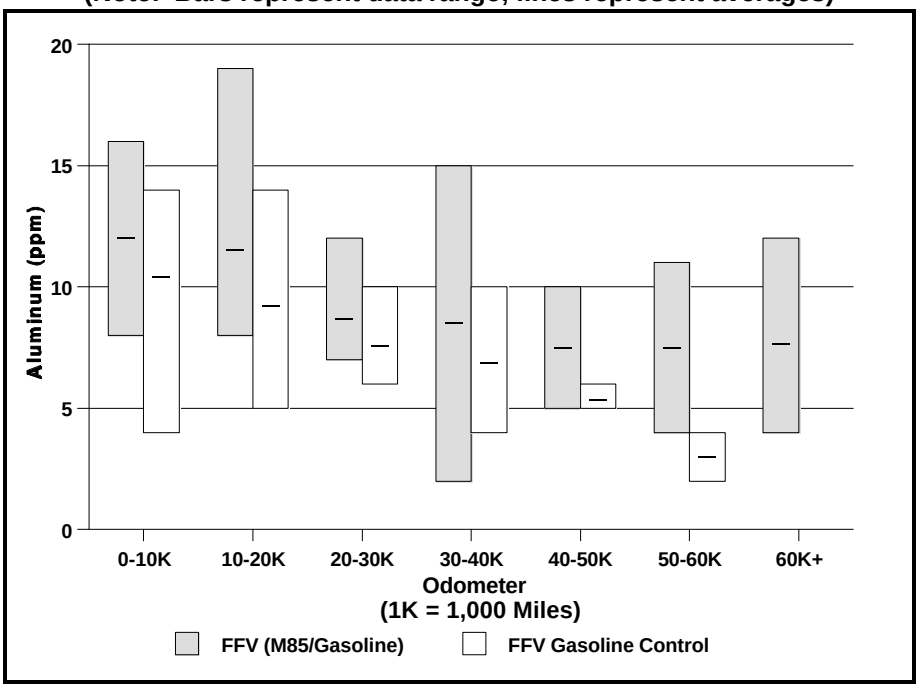


Figure 2.49 illustrates similar data for the White Plains Jetta operating on E85 and gasoline. This vehicle showed a larger difference in acceleration, needing 13.7 seconds to reach 60 mph on E85, and 15.1 seconds when operating on gasoline.

There are two primary characteristics of alcohol fuels that can improve FFV engine power: higher octane rating and a higher latent heat of vaporization. The higher octane rating allows the engine to operate with increased spark advance, increasing both engine efficiency and power. The latent heat of vaporization refers to the amount of heat required to vaporize the fuel. The higher the latent heat of vaporization of the fuel, the more heat will be transferred from the incoming air charge, resulting in a denser charge of fuel and air entering the cylinder which results in an increase in power.

Drivability. Starting problems during the cold winter months were initially present with the Monroe County FFVs operating on M85. This problem was traced to insufficient M85 RVP (7.5 psi) being used during the winter months. Subsequent M85 deliveries with higher RVP cured this problem. Drivability testing of the 1986 Ford Crown Victorias revealed some engine roughness during the first 30 seconds of operation after the engine hot soak sequence. The gasoline control vehicles had no starting problems during the period of data collection.

Figure 2.48 Taurus FFV Acceleration

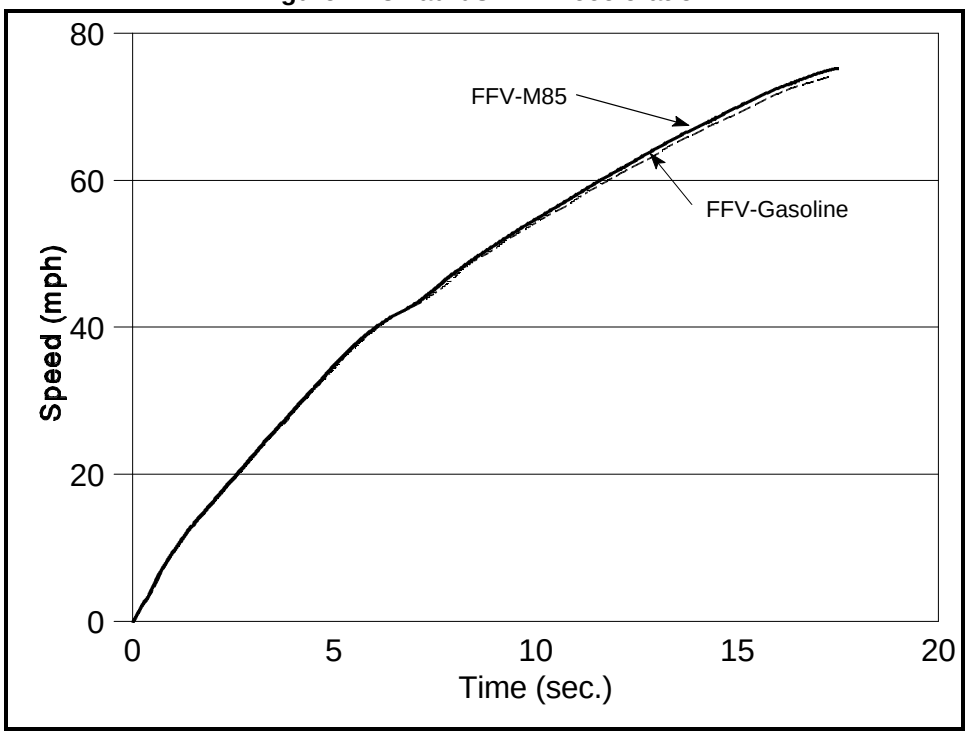
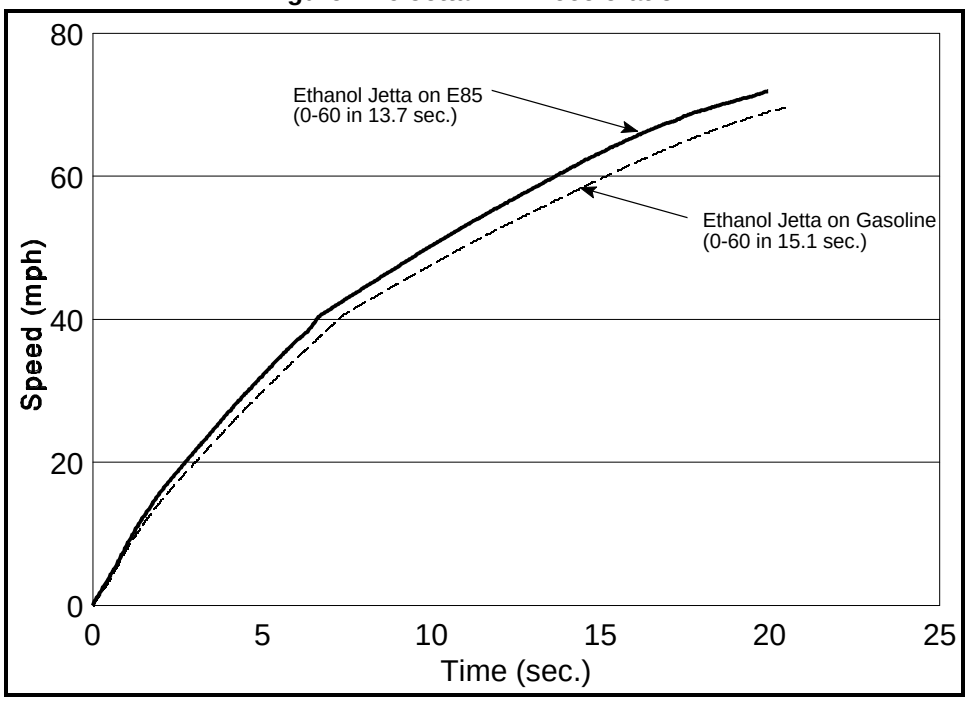


Figure 2.49 Jetta FFV Acceleration



FFVs using M85 appear to be inherently more difficult to start in cold weather than gasoline vehicles. This is likely predominantly because methanol does not vaporize as much as gasoline does at ambient temperatures typical of vehicle starting, and because methanol is conductive and will short circuit spark plugs wet with liquid methanol. As the outside air temperature drops, an M85 fueled vehicle adds more fuel to ensure that sufficient vapor is produced for cold-start. This increases the probability of the spark plug wetting and fouling. Once started and warmed up, the methanol and gasoline are ignited with no further problems.

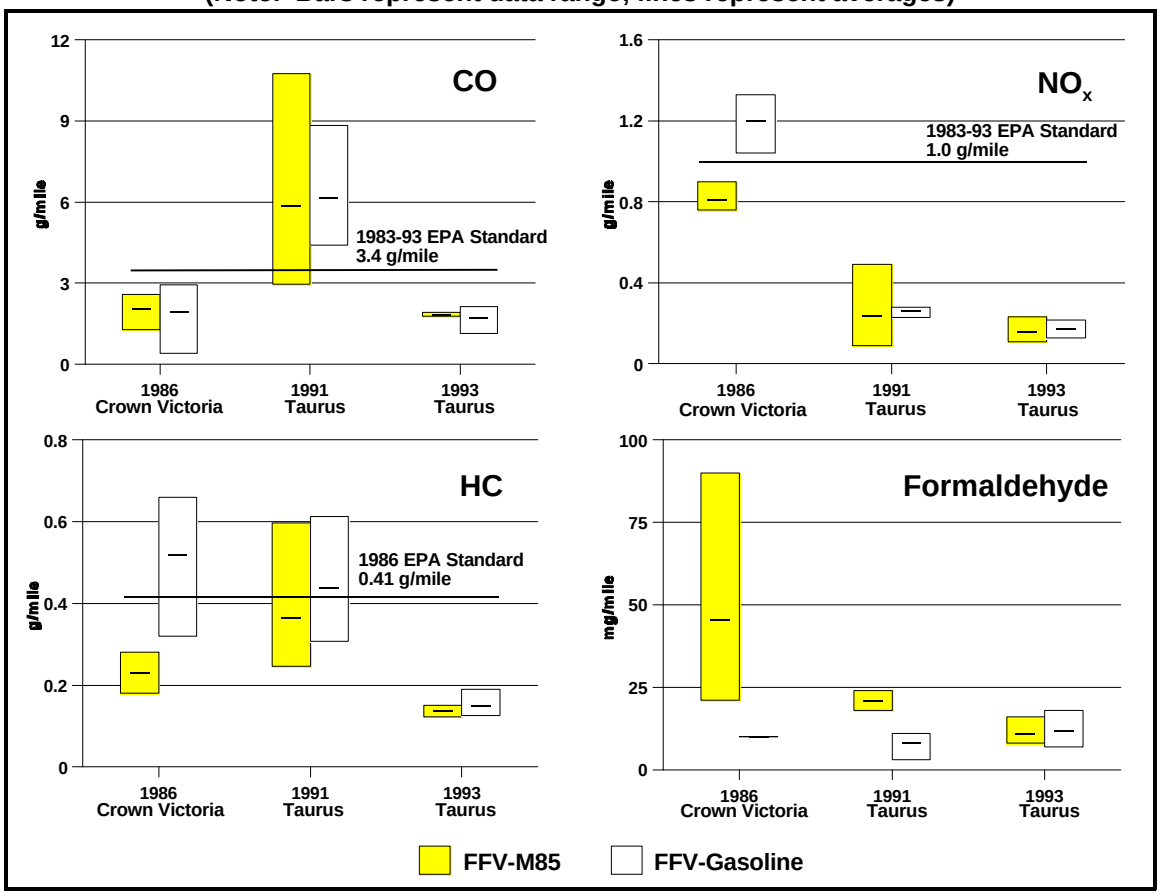
M85 fleets have sometimes chosen to add more gasoline to the methanol/gasoline blend during cold weather, which makes more gasoline available to vaporize so that the engine is able to start more reliably. The Thruway Authority did this during very cold weather during this demonstration by adding gasoline to vehicles with M85 in the tank. Starting problems during the cold winter months were initially present with the Monroe County FFVs operating on M85. This problem was traced to insufficient M85 RVP (7.5 psi) being used during the winter months. Subsequent M85 deliveries with higher RVP cured this problem.

A survey of how well the 1993 Ford Taurus FFVs performed in the Thruway Authority fleet was conducted. Drivers rated the power available with FFVs operating on M85 to be better than that available from similar gasoline vehicles. However, the drivers felt that FFV cold starting ability was inferior to that of conventional vehicles. In all other areas drivers rated M85 vehicle performance as equal to that of conventional gasoline vehicles. The fleet manager cited vehicle range on M85 as an area where FFV performance was lacking compared to gasoline vehicles.

Emissions. Emission tests on the FFVs were performed by the New York City Department of Environmental Protection (Frost Street Vehicle Emissions Testing Laboratory) in accordance with test procedures specified by the Environmental Protection Agency (the Federal Test Procedure or FTP). The exhaust of each test vehicle was sampled and analyzed for major emission constituents: CO, CO_2, hydrocarbons[35] (HC) and NO_x. Formaldehyde emissions were measured for comparison to levels generated by gasoline vehicles. Figure 2.50 presents the City Cycle emissions test results for the FFVs in the form of floating bars with the top of the bar representing the maximum, the bottom of the bar representing the minimum, and a line inside the bar indicating the average of the emissions sampled.

[35] Hydrocarbon measurements included everything in the exhaust containing carbon and hydrogen as measured using a flame ionization detector (FID). The FID response to methanol is typically between 60% and 80% of the actual concentration, resulting in reported values less than actual values.

Figure 2.50 Thruway Authority and Monroe County Methanol FFV City Cycle Emissions (Note: Bars represent data range; lines represent averages)



The 1986 Ford Crown Victoria FFV had lower HC and NO_x emissions on M85. The CO emissions were similar on M85 and gasoline. This FFV met all applicable emissions standards on M85; however, on gasoline it exceeded the HC and NO_x emissions standards. The formaldehyde emissions were significantly higher when using M85.

The 1991 Ford Taurus FFV was built and sold by Ford as an experimental vehicle and was not required to meet EPA standards for its model year. The 1993 Ford Taurus FFV was sold as a production vehicle in full compliance with EPA requirements. Results of emissions tests on these two vehicle types indicate that the 1991 vehicles did, in fact, exceed EPA emissions limits for CO and HC emissions while the 1993 FFVs were able to satisfy EPA emissions equally well using M85 or gasoline.

The 1993 Ford Taurus FFV is an improved version of an earlier M85 flexible fuel design, with refined fuel and emissions systems. Compared to the 1991 FFVs, results of emission tests on these vehicles indicate a

significant reduction in CO emission levels (approximately 70%) on the City Cycle. Reductions are also seen in NO_x (approximately 20%), hydrocarbon (approximately 70%), and formaldehyde emissions on M85 (approximately 50%). Comparing M85 to gasoline emissions, no significant difference was observed for all the emissions measured. For formaldehyde, this is a very surprising result since M85 typically produces many times higher formaldehyde emissions compared to gasoline, as illustrated by the Crown Victoria results.

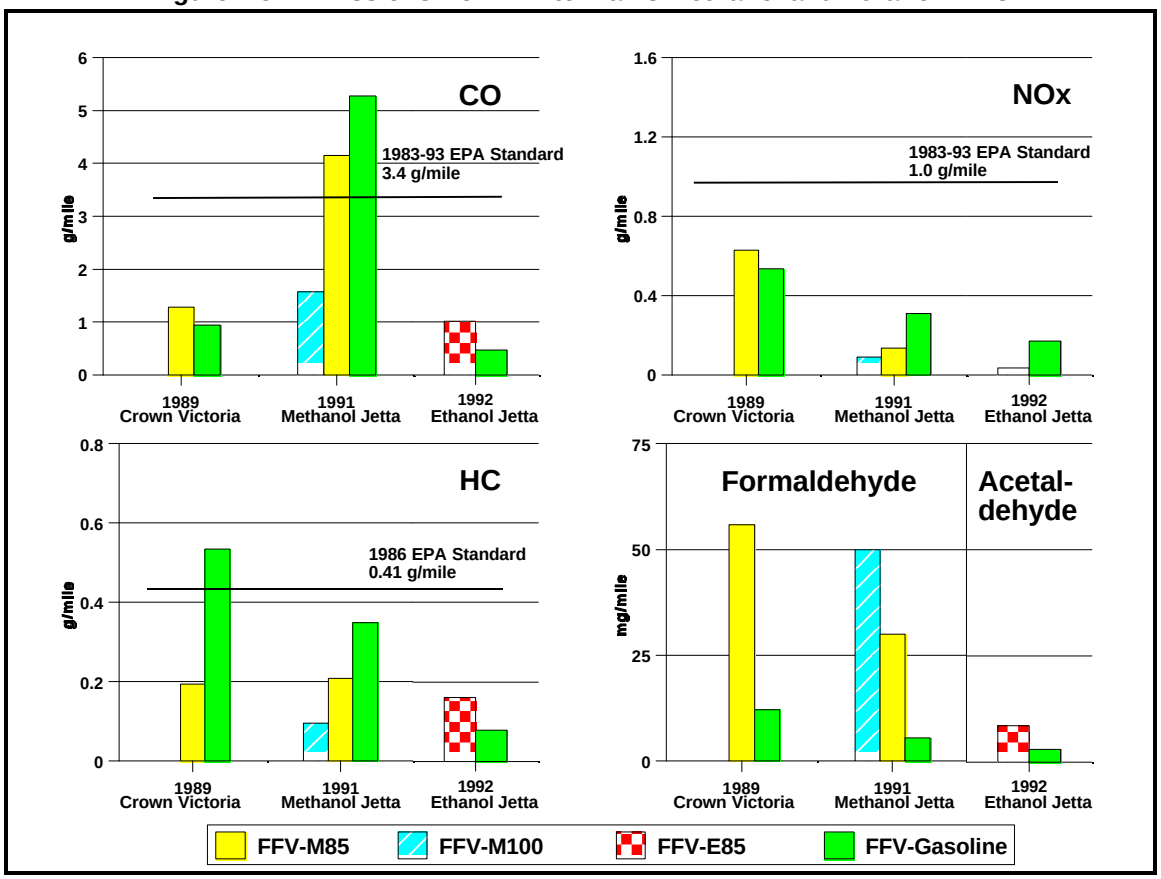
The FTP City Cycle emissions of the alcohol vehicles used by White Plains are presented in Figure 2.51. The Crown Victoria was tested using gasoline and M85; the methanol Jetta was tested using gasoline, M85 and M100; and the ethanol Jetta was tested using gasoline and E85. These emissions tests show that alcohol fuels can result in low emissions. The methanol Jetta appears to have been operating slightly richer than desired since its CO emissions using gasoline or M85 were above the standards for 1991 model vehicles. When using M100, CO emissions were reduced to less than half, presumably because of the higher amount of oxygen in the fuel. Both the Crown Victoria and the ethanol Jetta show low CO emissions.

Comparing HC emissions, all tests were within standards except for the Crown Victoria using gasoline. Both the Crown Victoria and the methanol Jetta showed decreases in HC emissions when using methanol fuels, while the Jetta showed an increase when using E85. These results suggest that the correct fuel system setting is more important than the fuel used for HC emissions.

Similar results occurred with NO_x emissions. All the tests were within the standards, but while the Jettas showed decreases in NO_x using alcohol fuels, the Crown Victoria showed a slight increase. There are fundamental reasons why combustion of alcohol fuels can result in reduced NO_x emissions from the engine, but the efficiency of the emissions control system is more important to tailpipe NO_x emissions.

Aldehydes (primarily formaldehyde and acetaldehyde) are products of incomplete combustion, and are produced when petroleum or alcohol fuels are combusted. Formaldehyde emissions predominate from methanol since formaldehyde is a methanol combustion intermediate. Similarly, acetaldehyde emissions predominate from ethanol combustion. The formaldehyde emissions of the methanol Jetta are illustrative of the effects methanol content of the fuel can have. In this methanol Jetta, M85 had about five times the formaldehyde emissions of gasoline, and M100 had about 10 times the formaldehyde emissions of gasoline. While these increases are large, the mass of aldehydes is much smaller than for the other emissions, and they can be significantly reduced from these levels as illustrated in Figure 2.50 for the Ford Taurus methanol FFV. Overall, the combined fuel and fuel systems tested were able to match emissions with current gasoline optimized fuel and emissions systems.

Figure 2.51 Emissions from White Plains Methanol and Ethanol FFVs



Fuel Costs. The price of methanol has moved up and down dramatically over the past few years. In the early 1990s methanol was purchased for use in the AFV-FDP for $0.50 per methanol gallon (before taxes) for a full tank truck delivery of 9,000 gallons. In 1995, an accident at a major methanol-producing facility in Texas and high demand for MTBE production caused the price of methanol to increase drastically, although the price has since returned to pre-1995 levels. The Gulf Coast spot price for methanol in the first nine months of 1996 varied between $0.35 and $0.50 per gallon with the median price being about $0.40 per gallon.[36] When distribution costs, dealer markup, and taxes are included, this translates to a pump price of methanol in the range of $0.77 to $1.13 per methanol gallon, depending on volume. Compared with gasoline at $1.17 per gallon, the cost of methanol for the same amount of energy would be $1.35 to $1.98 (gasoline gallon equivalent). Some of the literature indicates that in the long term, methanol could be cost-competitive with gasoline, but major investments would be necessary in production and distribution facilities. The major oil companies and other potential sources of private capital have to date not shown interest in promoting methanol,

[36] Hart's 21st Century Fuels, September 1996, Vol. 16, No. 9.

other than to invest in facilities to produce it for use in providing oxygenates (e.g., MTBE) in oxygenated and reformulated gasolines.

Ethanol used in the AFV-FDP was donated by New Energy, Inc., and much less experience is available to help estimate the price of ethanol if it were sold at commercial service stations in New York State. However, knowing typical wholesale prices for ethanol, and estimating transport and overhead costs, it is possible to determine a reasonable estimate of ethanol's pump price. Such an estimate yields a price range of $1.22 to $1.46 per ethanol gallon. Compared to gasoline at $1.17 per gallon, the cost of ethanol for the same amount of energy would be $1.83 to $2.19 (gasoline gallon equivalent). These numbers include the effect of preferential federal tax treatment that, if eliminated, would add more than $0.54 per gallon to ethanol's pump price. Ethanol is likely to remain an expensive fuel because its production process is inherently expensive. Researchers are developing ways to make ethanol from cellulose-based crops and waste products that eventually could make ethanol competitive in cost with gasoline.

Safety. No safety incidents related to the vehicles using M85 have occurred in the AFV-FDP. Specifically, no spills have occurred, no M85 has been ingested, and no fires have resulted from refueling or when vehicles have been in accidents. Reasons for this include safety training and the fact that all vehicle and refueling equipment is derived from gasoline service and is thoroughly proven.

During the AFV-FDP, local fire professionals were made aware of alcohol fuel operations so they were better prepared to respond in the event of a vehicle accident, fuel spill, or fire. Because they are common chemicals, both methanol and ethanol are already listed as UN1230 and UN1170, respectively.[37] Firefighters already have the information to respond to an accident/spill/fire situation with the proper equipment and response strategy.

Unlike gasoline, methanol and ethanol are soluble in water. In the case of a fuel spill, extra precaution must be taken to avoid contamination of drinking water, as methanol is poisonous. Unlike gasoline, water contaminated with alcohol will not be very noticeable to the public and ingestion problems could occur.

Technicians require training to minimize the risks associated with handling alcohol fuels and with alcohol vehicle operation and maintenance. Technicians need training to minimize contact with the fuels because of the potential health effects from inhalation or ingestion cited above. Gloves are recommended when fuel system maintenance is performed and the potential for substantial skin wetting is high. Goggles or face shields should be employed when there is potential for spraying of fuel under pressure such as during fuel injection

[37] 1993 Emergency Response Guidebook, USDOT RSPA P5800.6.

system maintenance. Ventilation of work areas is recommended whenever alcohol fuels are exposed to the air such as when fuel system maintenance is performed, fuel tanks are removed and emptied, etc. Anyone getting their clothes saturated with alcohol fuels should remove them immediately to prevent absorption of the alcohol through the skin.

Facility Modifications

Facilities designed to store and maintain gasoline vehicles need very little modification for methanol or ethanol vehicles. Eye-wash facilities should be installed (if not already present) to allow a person to quickly flush their eyes with water in the event methanol or ethanol is sprayed into them. Absorbent material to clean up spills needs to be available (used absorbent is a hazardous waste). In those facilities that have water and oil separators in their drainage systems, care must be taken to prevent methanol or ethanol from entering these separators for both safety and environmental reasons. Wastewater containing methanol or ethanol must be treated before being released.

In summary, the modifications of an existing fleet facility to include alcohol vehicles would require:

- Bringing the facility up to current codes and standards for conventional fuels
- Providing additional safety training for vehicle and refueling facility mechanics
- Purchasing of additional permanent and disposable protective equipment (gloves, face shields/goggles, eye wash, etc.)
- Alerting emergency/fire personnel of the existence of alcohol fuel operations.

Other Demonstrations

During the course of the AFV-FDP, there were demonstrations of AFVs across the country. Most of these did not collect comparable data to that collected by the AFV-FDP. There were two notable exceptions:

- The U.S. Department of Energy collected data from AFVs in the Federal Alternative Motor Fuel Program (AMFA) program, and other AFVs in the Federal fleet implemented according to President Bush's and President Clinton's executive orders. The data were collected and analyzed by the National Renewable Energy Laboratory (NREL) in Golden, Colorado.[38]

[38] Whalen, P., et al., "Summary of Results from the National Renewable Energy Laboratory's Vehicle Evaluation Data Collection Efforts," May 1996. Available from the World Wide Web (http://www.afdc.nrel.gov) or from the National Alternative Fuels Hotline (1-800-423-1DOE).

- Federal Express conducted a demonstration called The CleanFleet Program in the Los Angeles area.[39, 40, 41, 42, 43, 44] The AFVs used in this demonstration were typical Federal Express light-duty delivery vans, similar to most of the AFVs used in the AFV-FDP.

Overviews

DOE. Data were collected from the Federal AFVs over the period of 1991 through 1995. During this time, the number of Federal AFVs of all types increased to over 15,000. The AFVs were distributed among several Federal agencies around the country. They were operated under a wide variety of climatic conditions at a wide range of altitudes, performing numerous tasks. Table 2.20 lists the alcohol vehicle models and gasoline control vehicles from which data were taken.

Federal Express. The Federal Express CleanFleet demonstration included five different alternative fuels and gasoline used in 111 light-duty delivery vans. The demonstration was conducted in southern California and data were collected for a period of 24 months. The M85 vehicles included were 20 Ford Econoline FFV vans similar to those in the DOE demonstration.

Fuel Economy. A summary of the differences in the FTP City Cycle fuel economy of the alcohol vehicles included in the AFV-FDP, DOE, and Federal Express demonstrations is presented as Table 2.21. The largest difference in fuel economy was +12% for the Monroe County Taurus FFVs using M85. However, this model Taurus FFV was not certified to meet emission standards. The Thruway Authority and DOE Taurus FFVs showed +3% and -3% differences, respectively. The DOE Spirits and Econoline FFVs showed a -7% change in fuel economy when using M85. Since these were the first and only FFV

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[39] Sverdrup, G.M., et al., "The CleanFleet Alternative Fuels Demonstration Project," SAE Paper No. 912665, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1991.

[40] Sverdrup, G.M., et al., "Vehicle Emissions Results - CleanFleet Alternative Fuels Project," SAE Paper No. 960394, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1995.

[41] Herridge, J.T. and J.E. Lambert, "Fleet Economic Analysis - CleanFleet Alternative Fuels Project," SAE Paper No. 950396, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1995.

[42] Orban, J.E., M.J. Murphy, and M.C. Matthews, "Vehicle Fuel Economy - CleanFleet Alternative Fuels Project," SAE Paper No. 950397, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1995.

[43] Murphy, M.J., "Safety and Occupational Hygiene Results - CleanFleet Alternative Fuels Project," SAE Paper No. 950397, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1995.

[44] Alexander, G.H., et al., "Vehicle Reliability and Maintenance - CleanFleet Alternative Fuels Project," SAE Paper No. 950398, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1995.

Table 2.20 DOE Alcohol Test and Gasoline Control Data Collection Vehicles

Vehicle Model	Model Year				
	1991	1992	1993	1994	1995
Chevrolet Lumina	21 M85 8 Gasoline	21 E85	34 E85 29 M85 39 Gasoline		
Ford Econoline Van		14 M85	3 M85 20 Gasoline		
Ford Taurus	36 M85 8 Gasoline		16 M85 26 Gasoline	16 E85	
Dodge Spirit			279 M85 88 Gasoline	13 M85	
Dodge Intrepid					8 M85 10 Gasoline

models of each, it is possible that they were not as well optimized for fuel economy as the other FFVs. It is noteworthy that the in-use fuel economy difference for the Thruway Taurus FFVs was +7% based on 2.3 million miles of operation. None of these vehicles were optimized specifically for M85. It appears safe to assume that current technology FFVs using M85 will have very similar fuel efficiency as when using gasoline.

The three vehicle models using E85 all showed positive changes in fuel economy from +3% to +8%. These positive results are from a relatively small data set and it would be premature to suggest that there is a significant difference in fuel economy for FFVs using E85 versus using M85.

Drivability. Drivers in the DOE demonstration were requested to submit drivability complaints as they occurred according to the categories: hesitation, check engine light, hard to start, poor idling, lack of power, pinging, stalling after start, and stalling in traffic. The 1991 model FFVs had significantly more complaints than for the gasoline control vehicles. Improvements were noted with each successive model year such that the 1994 FFVs had insignificant differences in drivability compared to the gasoline control vehicles. Surprisingly, no mention of increased cold-start problems during cold weather was noted. Also, feedback about reduced driving range apparently was not solicited. The Federal Express CleanFleet demonstration apparently did not collect drivability data. Neither demonstration apparently collected any acceleration data.

Reliability. In the DOE demonstration, unscheduled repairs were about 2.5 times greater for the 1991 model year FFVs using M85 compared to similar gasoline vehicles. In each successive model year,

Table 2.21 Comparison of Fuel Economy Among Demonstrations

Model		Gasoline[1]	M85[2]	E85[2]
DOE Lumina	mpg	19.1	19.5	20.2
	Percent change	--	+2	+6
DOE Spirit	mpg	24.0	22.3	--
	Percent change	--	-7	--
DOE Econoline	mpg	15.0	13.9	--
	Percent change	--	-7	--
DOE Taurus	mpg	21.4	20.7	22.0
	Percent change	--	-3	+3
Federal Express Econoline	mpg	13.8	13.6	--
	Percent change	--	-1	--
AFV-FDP Thruway Taurus	mpg	21.7	22.3	--
	Percent change	--	+3[3]	--
AFV-FDP Monroe Co. Taurus	mpg	19.5	21.9	--
	Percent change	--	+12	--
AFV-FDP White Plains Jetta	mpg	24.9	--	26.9
	Percent change	--	--	+8
AFV-FDP White Plains Jetta	mpg	24.9	25.0	--
	Percent change	--	0	--
AFV-FDP White Plains Crown Victoria	mpg	18.6	18.4	--
	Percent change	--	-1	--

[1] For the DOE vehicles, gasoline fuel economy is from control vehicles; for the AFV-FDP vehicles, gasoline fuel economy is from the same FFVs using alcohol and gasoline fuels.
[2] Gasoline-equivalent fuel economy.
[3] For the Thruway Authority Taurus FFVs, the in-use fuel economy difference was +7%.

unscheduled repairs decreased and are approaching the levels of gasoline vehicles. In the Federal Express CleanFleet demonstration, the M85 FFVs had problems with injectors and two vehicles had fires caused by the cold-start injectors. Four of the 20 FFVs had their fuel pumps replaced. These problems were typical of those encountered in the 1991 model year Monroe County Taurus FFVs (except for the fires).

Based on the AFV-FDP and DOE demonstrations it is apparent that M85 FFV reliability has increased and is nearly equivalent to gasoline models.

Emissions. The DOE demonstration presented emissions results only from the Spirit and Econoline FFVs using M85. HC and CO emissions declined slightly when using M85 compared to gasoline. Emissions of NO_x increased slightly and emissions of formaldehyde increased by four to five times. Similar results were observed in the Federal Express CleanFleet demonstration except that CO emissions were reduced on average by about 50%. Overall results from both demonstrations were similar to those from the AFV-FDP.

Lessons Learned

Based on the data collected and analyzed during the AFV-FDP, several observations about light-duty alcohol FFVs were made:

- FFVs have similar drivability and acceleration performance as their counterpart gasoline models.
- Fuel quality is very important to FFV engine durability and must be monitored closely until M85 and E85 distribution systems are established.
- Fuel specifications must be adhered to closely or else cold-start problems are likely in cold weather.
- M85 and E85 FFVs have reliability and durability approaching their gasoline counterparts.
- Reduced operating range is the largest drawback of FFVs using M85 or E85.
- Fuel economy on an energy-equivalent basis is the same to slightly improved for FFVs using M85 or E85 compared to using gasoline.
- Mass emissions are similar for FFVs using M85 or E85 relative to using gasoline and ozone forming potential is decreased.
- M85 and E85 generate greenhouse gases approximately equal to gasoline, when the full fuel cycle is accounted for.
- Energy-equivalent prices of M85 and E85 are two to three times higher than gasoline.
- Refueling facilities for M85 and E85 are simple variants of current gasoline facilities (upgrades for materials compatibility purposes only).
- Maintenance personnel need to be educated about safe fuel handling practices and health effects due to exposure and ingestion of M85 and E85.