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The Ethanol Heavy-Duty Truck Fleet Demonstration Project

Illinois Department of Commerce and Community Affairs
Springfield, Illinois

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Executive Summary

Until recently, the use of ethanol-based fuels for transportation has been limited to a few small, isolated projects. Of these projects, most were performed by engine and vehicle manufacturers, making them proprietary in nature. As a result, very little was known about the performance, durability, economics, and emissions of heavy-duty vehicles operating on ethanol fuels.

In March 1992, the first fleet of four ethanol-powered, heavy-duty, over-the-road trucks in the country were put into service. The four trucks, White-GMC WIM-64T models, were equipped with specially modified Detroit Diesel Corporation (DDC) model 6V-92TA engines. The engines were rated at 300 horsepower and used E95, a fuel composed of 95% anhydrous ethanol and 5% light hydrocarbon denaturant. These ethanol trucks, along with an identical fifth truck equipped with a conventional DDC 6V-92TA diesel engine, were owned and operated by Archer Daniels Midland (ADM) Trucking, Incorporated, based in Decatur, Illinois. The trucks were used almost evey day for deliveries to points in Illinois, Indiana, Iowa, and Missouri. One of the ethanol trucks in the fleet accumulated more than 325,000 miles without a major overhaul.

As a result of this project, a considerable amount of data was recorded for the first time on the performance, durability, economics, and emissions of heavy-duty trucks operated on ethanol fuel. The project is considered a success, and the primary conclusion we can draw is that ethanol engines are capable of the same, or better, performance, durability, and emissions as diesel engines. The cost of operating an ethanol vehicle, however, is more than twice that of a conventional diesel engine because of the special engine parts and lubricants used, and because ethanol costs approximately 1.8 times more than diesel on an equivalent energy content basis.

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Introduction

The American transportation sector uses more than 30% of all the energy consumed in this country each year. Conventional hydrocarbon fuels, primarily gasoline and diesel fuel, represent the current sources of energy for transportation. Naturally occurring hydrocarbon reserves, however, exist in finite quantities and are very limited in geographic extent. Proven worldwide hydrocarbon reserves are being depleted faster than they are being discovered, and more than 50% of the petroleum used annually for energy in America is imported.

Heavy-duty trucks and urban transit buses account for a large portion of the U.S. transportation sector. For the most part, these vehicles are powered by compression-ignition diesel fuel engines, which typically emit high levels of oxides of nitrogen (NO_x), uncombusted and partially combusted hydrocarbons (HC), and black particulate smoke during operation. The black particulate smoke is not only unsightly, but has proven to be carcinogenic.

Ethanol, also know as ethyl alcohol, is a renewable energy resource generated through the biological fermentation of simple glucose sugars. At this time, the ethanol industry in the United States has an annual production capacity of approximately 1.6 billion gallons. Although ethanol can be made from a wide variety of feedstocks, corn is generally used to produce ethanol in this country because of its abundance and relatively low price considering the amount of ethanol that it yields.

Hydrocarbons are normally locked deep within the earth where they are physically isolated from the environment. The combustion of these hydrocarbon fuels for energy, then, represents a new source of carbon dioxide (CO_2) to the atmosphere. It can be argued that the combustion of ethanol, because it is derived primarily from plant material that uses CO_2 during photosynthesis, recycles the CO_2 back to the atmosphere where it originated. Because of this, the use of ethanol as a fuel for transportation would effectively minimize greenhouse gas emissions with respect to CO_2.

Ethanol has been successfully used as an additive in gasoline in many parts of the country since the 1970s. This fuel formulation, also called "gasohol," is composed of 90% unleaded gasoline and 10% ethanol. In this application, ethanol can be considered a petroleum extender, an octane enhancer, and an oxygenate additive to gasoline.

From an emissions standpoint, numerous studies have shown that gasoline blended with 10% ethanol reduces carbon monoxide (CO) emissions from internal combustion engines by as much as 25%. Ethanol-blended gasolines are being used in many of the nation's cities currently in non-attainment for CO levels. Until recently, very little was known, however, about emissions from vehicles designed to operate on higher percentage blends of ethanol fuel.

Until the 1990s, the use of high-percentage blends of ethanol fuels for transportation has been very limited. Henry Ford was the first American automobile manufacturer to see the potential of ethanol as a fuel in the early 1900s. Many of his early Model A automobiles were capable of operating on ethanol fuel rather than gasoline. Since then, only a few isolated testing programs (most of which have been performed by vehicle and engine manufacturers and contain proprietary information) have been designed to test, demonstrate, and evaluate the use of ethanol as a viable alternative transportation fuel in light-, medium- and heavy-duty vehicles.

This project, then, was designed to test and demonstrate the use of a high-percentage ethanol-blended fuel in a fleet of heavy-duty, over-the-road trucks, paying particular attention to emissions, performance, and repair and maintenance costs. This project also represents the first public demonstration of the use of ethanol fuels as a viable alternative to conventional diesel fuel in heavy-duty engines.

Project Background

Illinois is the leading producer of ethanol in the country and is the second largest annual corn producer in the nation. The use, testing, and demonstration of high-percentage blends of ethanol as alternative fuels in Illinois, then, is a logical choice. Further, both corn and ethanol are vital to the economy of the state.

In 1990, the Illinois Department of Energy and Natural Resources (ENR), through the Alternative Energy Development Section (AE Section), was the state agency responsible for testing, developing, and implementing alternative fuel programs in Illinois. As of July 1, 1995, however, ENR ceased to exist as an independent state agency. The AE Section, along with the Ethanol Heavy-Duty Truck Fleet Demonstration Program, became part of the Illinois Department of Commerce and Community Affairs (DCCA). DCCA is located in Springfield, the state capital of Illinois.

In September 1990, staff from the AE Section at ENR developed the original draft proposal for this project. The proposal called for a total of four fleets of five vehicles each (a total of twenty vehicles) with a estimated budget of $828K. This unsolicited proposal was then submitted to the Solar Energy Research Institute (SERI) in Golden, Colorado, for consideration. (Note: In 1991, SERI was upgraded to a national laboratory and renamed the National Renewable Energy Laboratory (NREL). For the purpose of this report, the acronym "NREL" will be used to represent both NREL and SERI). Meanwhile, ENR staff members met with several managers of prospective truck fleets located in Illinois to discuss the project. Although several fleet managers were highly interested in participating in the program, the costs, fuel supplies, fuel availability, and other logistical problems arose. Of the fleet operators ENR staff met with, the most logical choice as the first fleet operator was Archer Daniels Midland (ADM). ADM is the largest producer of ethanol in the country and is based in Decatur, Illinois. ADM Trucking, Inc., operates more than 800 heavy-duty trucks and trailers that deliver agricultural products such as ethanol, high-fructose corn syrup, and liquid CO_2 throughout the Midwest. ADM Trucking, Inc., is also based in Decatur and is within a half mile of the main ADM production facility. Because E95 is produced at the main facility, it was readily available for use in the trucks.

For these reasons, then, ADM was chosen to operate the first fleet of ethanol-powered trucks in the country. ADM representatives visited Detroit, Michigan, to meet with DDC's engineering staff. On their return from Detroit, ADM ordered five conventional 6V-92TA diesel trucks (Figure 1). The trucks were assembled by White-GMC in North Carolina in November 1991. One of the trucks, the control diesel, was shipped directly to ADM; the other four units were shipped to DDC in Detroit to be converted to ethanol operation. The four trucks were converted and arrived in Decatur in March 1992. The diesel unit, #92010, was operating for about 3 months before the ethanol units went into service.

A four-person negotiating team from NREL came to Springfield in June 1992 to discuss the terms of the contract. After several days of negotiations with DDC, agreement was reached on the terms of the contract. The main contract was between NREL and ENR, with ENR serving as the primary subcontractor to NREL. ENR, in turn, initiated its own subcontracts with DDC, ADM, and for actual field implementation of the project. The original proposal was modified to one fleet of four ethanol-powered trucks at a cost of $368K.

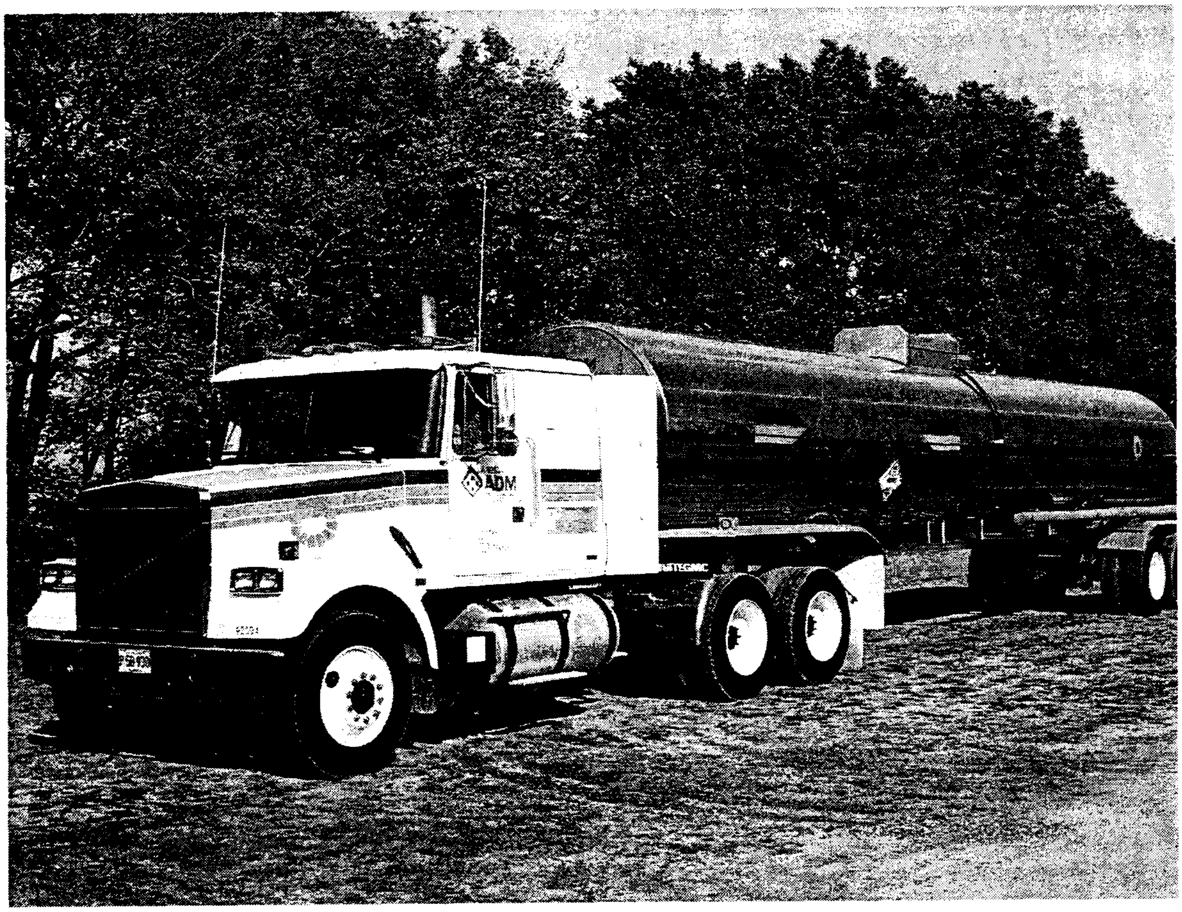

Figure 1. The White-GMC WIM-64T Heavy-Duty Truck

With NREL as the primary funding source, ENR was responsible for partial equipment funding; additional funding for field service and maintenance support for the trucks beyond the first 2 years of the project; personnel time for data collection, interpretation, and project coordination; submission of data and invoices from the project to NREL; and distribution of funds received from NREL to DDC and ADM for equipment and services rendered on the project.

Although the primary participants in the project were NREL, ENR (now DCCA), ADM, and DDC, the Illinois Corn Growers Association (ICGA) joined the project soon after its inception as a secondary participant assisting in the promotion of the program.

Engines and Vehicles

The DDC Model 6V-92TA (with the **TA** denoting **T**urbocharged and **A**ftercooled) powerplant was selected as the engine for the four ethanol trucks. The 6V-92TA (Figure 2) alcohol fuel engine is a vee-configuration, six cylinder, two-cycle motor capable of producing up to 300 horsepower. The methanol version of the engine was first developed in1986 and emissions certified (by the U.S. Environmental Protection Agency [EPA] and the California Air Resources Board [CARB]) in 1991 for use in urban transit buses in California. DDC's previous experiences with the methanol 6V-92TA engine aided the development of the ethanol version of the 6V-92TA engine in 1991 and its emissions certification in 1992. By late 1992, DDC considered both alcohol engines standard production engines.

In 1992, the primary use of the DDC 6V-92TA diesel engine was as a powerplant for urban transit and touring coach buses. DDC selected the 6V-92TA engine for development as an alcohol fuel engine for at least two reasons: (1) the 6V-92TA diesel engine was used in about 80% of the urban transit buses currently on the road, and (2) the two-cycle engine was easier to convert to alcohol fuel than a four-cycle engine. A two-cycle engine removes combustion products close to the bottom of the piston stroke by means of a blower to push out the exhaust gases (called "scavenging"). Scavenging causes mixing of hot exhaust gases with the new fuel mixture to be combusted. The presence of these hot exhaust gases in the cylinder raises the fuel temperature, making compression ignition of low-cetane fuels such as ethanol much easier. As a result, two-cycle engines have a distinct advantage over four-cycle engines in compression igniting fuel with high auto-ignition temperatures.

DDC also modified some of the components on the ethanol 6V-92TA engines. The first of these major modifications was to the Detroit Diesel Electronic Controls (referred to as DDEC II), which contains the electronic control module (ECM) and the electronic unit (fuel) injectors (EUI). The ECM is the on-board computer for the engine that controls various engine operations under continuously varying conditions to optimize performance, fuel economy, and emissions. The ECM receives electronic signals from the truck's driver in addition to engine-mounted sensors. The electronic hardware in the ECM contains a PROM (Programmable Read Only Memory) encoded with the specific engine performance characteristics (such as horsepower rating, torque curve, and maximum engine speed). In order to use ethanol fuel, the ECM must be specifically programmed for ethanol fuel at the factory or by a DDC field engineer.

The second part of the DDEC II unit, the EUI, contains an electronically controlled solenoid valve that meters and times fuel input to the cylinders. Because ethanol contains only about 60% of the energy of diesel fuel per unit volume, more ethanol fuel is required to generate the same amount of power in the engine. This is accomplished by increasing the diameter of the spray holes in the EUI

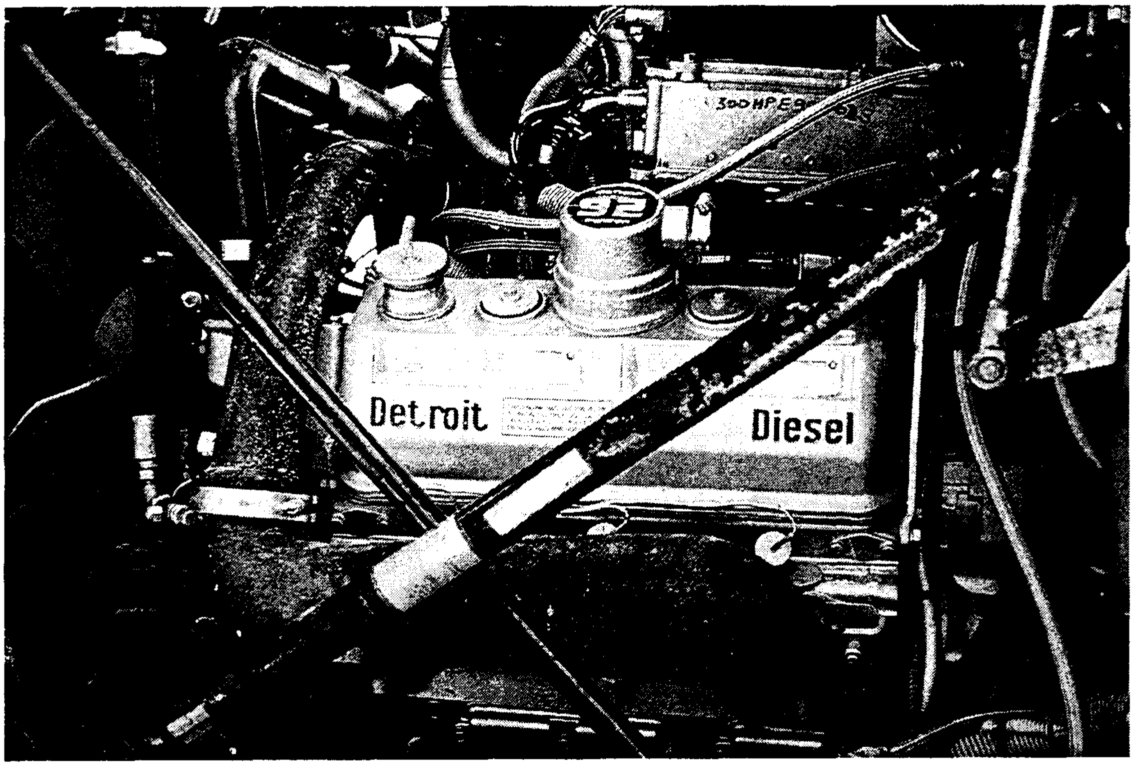

Figure 2. The DDC 6V-92TA 300 Horsepower Ethanol Engine

tip. The EUI can then inject the proper amount of ethanol fuel into the cylinder at the correct time without reducing the engine performance.

Next, the bypass air system was modified. This system provides the correct metering and mixing of retained hot exhaust gases and fresh air in order to achieve the proper ethanol compression ignition temperature. The bypass air system is controlled by the DDEC II unit and changes settings of the system based on changes in operating conditions of the engine.

The ethanol 6V-92TA engines also use a glow plug system that has been modified for use with the DDEC II system. The glow plugs are electronically heated and are used to help start the engine. The glow plugs remain on (heated) for one minute prior to starting the engine and remain on until the engine coolant reaches normal operating temperature.

Another major modification to the ethanol engine is an increased compression ratio as compared to the conventional diesel version. The ethanol engine has a compression ratio of 23:1 compared to 18:1 for the diesel. This increase is needed to ensure complete combustion of the ethanol fuel in the cylinder and to maximize engine performance and torque.

The final major modifications to the four ethanol trucks were to the fuel system. Because ethanol is more corrosive to certain metal, plastic, and rubber parts, stainless-steel fuel tanks and fuel lines were added. The capacity of each of the two fuel tanks was 120 gallons per tank, the same capacity as on the diesel truck. Also, because more ethanol fuel is required to deliver the same performance, twin, larger, ethanol-resistant fuel pumps were added.

The use of the DDC 6V-92TA ethanol engine in a heavy-duty, over-the-road truck application was limited to a relatively small number of vehicles with compatible engine compartments and frames. One specific model, the White-GMC WIM-64 tractor, was chosen by ADM Trucking, Inc., as the best fit for their transportation needs. The four ethanol trucks were designated ADM Units #92002, #92004, #92006, and #92008,and the conventional diesel control truck was designated ADM Unit #92010. The four ethanol engines used in this program were each rated at a maximum of 300 brake horsepower at 2,100 rpm. Maximum torque of 975 foot pounds was achieved at 1,200 rpm.

The five new 1992 White-GMC WIM-64T model tractors were identically equipped. Each was a 6 x 4 axle configuration; 6 total wheels with 4 drive wheels. The transmissions were all nine forward speeds (Rockwell RTX 12609B) with one reverse gear and each truck was equipped with two 120- gallon fuel tanks. Identical 11 x 24.5 standard radial tires were used on all vehicles. Curb weight of the vehicles was 23,688 pounds with a gross vehicle weight (GVW) rating of 80,000 pounds.

E95 Ethanol Fuel

Ethanol (also called ethyl alcohol) is an oxygenated hydrocarbon with the chemical formula of C_2H_5OH. Ethanol is a by-product of the fermentation of simple glucose sugar by yeasts. Anhydrous (less than 0.5% water concentration by volume) ethanol contains 76,000 Btu of energy per gallon and is almost infinitely miscible with water (Table 1).

The "proof" of an alcohol is defined as twice the percentage of alcohol in the solution. For example, a mixture of 90% pure ethanol and 10% water is referred to as "180-proof" ethanol.

For all practical purposes, there are two types of industrial-grade ethanol: anhydrous and hydrated. Anhydrous ethanol is defined as at least 99.5% pure ethanol, with less than 0.5% water by volume. Anhydrous ethanol is also called "200 proof" ethanol or gasoline grade ethanol, as this is the concentration of ethanol blended with gasoline to make "gasohol." Hydrated ethanol is any other ethanol blend containing more than 0.5% water by volume. In either case, fuel-grade ethanol must be denatured with 2% to 5% denaturant to make it unfit for human consumption. Otherwise, it is highly taxed by the U.S. Department of the Treasury, Bureau of Alcohol, Tobacco, and Firearms (ATF) as beverage-grade alcohol. Some of the denaturants commonly used include methanol, benzene, toluene, natural gasoline, kerosene, and unleaded gasoline.

The cetane number (Table 2) of a fuel, as compared to diesel fuel, is indicative of the ease (or difficulty) by which a fuel can be ignited and combusted in a diesel engine. Fuels with high cetane numbers have low autoingition temperatures and short ignition delay times. E95 has a low cetane number of only 8, compared to 3 for methanol, and 40 to 50 for diesel fuel. This indicates that the alcohol fuels have higher autoignition temperatures than does diesel fuel. This is reflected in the

Table 1. Fuel Comparisons

	Diesel	**Ethanol**	**Methanol**	**CNG**
Composition	Various	C_2H_5OH	CH_3OH	CH_4
Btu/Gallon	130,000	76,000	57,000	N/A
Cetane Number	40–50	8	3	N/A
Octane (RON)	N/A	108	107	130
Water Solubility	0	Infinite	Infinite	N/A
Reid Vapor Pressure (psi)	0.2	2.3	4.6	2400
Boiling Temperature (F)	370–650	172	149	-259
Freezing Point (F)	-70	-173.2	-143.5	-296
Auto Ignition Temperature (F)	600	793	867	1004

Table 2. Fuel Properties

	Diesel	Ethanol	Methanol	CNG
Cetane	High	Low	Low	N/A
Natural State	Liquid	Liquid	Liquid	Gas
Fuel Tank Pressure	Low	Low	Low	High
Toxicity	Toxic	Toxic in large doses	Very toxic	Toxic
Corrosiveness	Minimal	Corrosive	Very corrosive	Minimal
Cost of Refueling Facility	Normal	Slightly increased	Slightly increased	Very expensive
Refueling Time	Normal	Normal	Normal	Slow

autoignition temperatures of 495°F for diesel fuel, 793°F for ethanol, and 867°F for methanol. As a result, improving the autoignition of E95 in the 6V-92TA engines requires glow plugs on the 6V-92TA ethanol engine that are "on" for one minute before the engine is started, and remain on until the engine heats up to normal operating temperature.

Diesel fuel is a complex mixture of hydrocarbons, and its composition can vary widely from "batch to batch." Because of this wide variation, the energy content of #2 diesel fuel is assumed to average about 130,000 Btu per gallon.

The fuel formulation used in the four 6V-92TA truck engines in this project is a blend of 95% anhydrous ethanol and 5% natural gasoline denaturant. (This is the same denatured ethanol blended with gasoline to make E10 or gasohol). This ethanol fuel is called E95, but it can also be called E(d)-100, with the "d" standing for denatured. (For consistency, the term E95 will be used throughout this paper whenever ethanol fuel is discussed). The denaturant used by ADM, natural gasoline, is a mixture of primarily four to seven carbon hydrocarbons, without the heavier hydrocarbons and aromatics used to enhance the octane level of unleaded gasoline. Natural gasoline is the first distillate product of petroleum cracking at the refinery. In this case, natural gasoline serves not only as a denaturant in E95 fuel, but adds volatility to the fuel mixture and makes the fuel easier to ignite, especially in cold weather. Because of the 5% natural gasoline denaturant in the ethanol fuel, the overall energy content of the fuel is increased to 78,000 Btu per gallon, or 60% of the energy content of diesel fuel (assumed to be 130,000 Btu per gallon). The total capacity of the two fuel tanks on the ethanol trucks is 240 gallons, of which 95% of the total volume, 228 gallons, is usable. At the average of 3.2 miles per gallon on E95, the maximum range of each ethanol truck is approximately 730 miles. By contrast, the maximum range of the conventional diesel control unit, which uses the same size fuel tanks as the ethanol trucks, is 1,345 miles based on an average 5.9 miles per gallon of diesel fuel. Due in part to the limited range of the ethanol trucks, they were driven to destinations that allowed them to return to the facility in Decatur every night.

E95 differs from the E93 used in the 14 6V-92TA ethanol-powered buses currently being operated by the Greater Peoria Mass Transit District. The E93 fuel formulation was adopted in order to allow GP Transit, a nontaxable municipal entity, to take advantage of the alcohol tax credit. E93 fuel is composed of 93% anhydrous ethanol, 5% "synthetic" (made from natural gas) methanol, and 2% kerosene denaturant. The energy content of the two ethanol fuels is nearly identical.

Compared to the other currently available alternative fuels, ethanol fuels offer a number of distinct advantages (Table 2). Ethanol is a liquid fuel that does not need to be pressurized like compressed natural gas (CNG). This also allows greater range between refuelings. The fuel tanks on the truck can be filled by using conventional (albeit ethanol-tolerant) dispensing equipment. Refueling time is very similar to that of diesel fuel.

Ethanol, like methanol, is known to be corrosive to certain metal, plastic and rubber parts. However, ethanol is considered much less corrosive than methanol and the general rule of thumb is that if a part can be used for methanol, it can easily be used for ethanol. Ethanol is also less toxic than methanol and, because methanol only contains about 57,000 Btu per gallon, ethanol vehicles have greater range with the same size fuel tanks.

One problem encountered with using ethanol fuels is that they do not have the same lubricating properties of conventional, petroleum-based fuels. In order to ensure upper cylinder lubrication, an additive developed in California for the methanol buses, Lubrizol, is added to fuel in very low concentrations. The recommended amount of Lubrizol is 0.06%, by volume, (2.27 milliliters per gallon) in the fuel mixture and was regularly added to the E95 fuel used in all four ethanol trucks.

The market price of gasoline-quality anhydrous ethanol in central Illinois closely tracks the price of gasoline and diesel fuel. As a very general rule, the price per gallon of ethanol (E95) is about $0.10 more than the retail pump price of unleaded gasoline. It is estimated that the average price of ethanol has been about $1.18 per gallon during the course of this project as compared to an average price of about $1.08 per retail gallon of diesel fuel. Because E95 has a lower energy content than diesel fuel, these prices cannot be compared directly. A diesel equivalent gallon is the quantity of E95 that has the same energy content as a gallon of diesel fuel. By expressing the price of E95 in diesel equivalent gallons, we can compare its price with the price of diesel fuel directly. The cost of E95 fuel used in this project, then, was about $1.97 per diesel equivalent gallon. These figures will be used throughout this report to determine the economics of using ethanol as a transportation fuel.

Application of the Alcohol Tax Credit (Appendix 1) greatly reduces the cost of E95 and, therefore, the cost of operating a fleet of vehicles on E95. Congress developed the alcohol fuel credit in response to the energy crisis of the late 1970s and early 1980s. The intent was to foster growth of the alcohol industry by subsidizing nonpetroleum-based alcohol used as fuel so the cost for the end user would be comparable to traditional hydrocarbon fuels. The tax credit is accomplished in two ways: (1) by granting a 5.4¢ per gallon partial excise tax exemption for 10% alcohol blended fuels (gasohol) and (2) by allowing a 54¢ per gallon income tax credit for ethanol used as a fuel. The income tax credit is available to taxpayers who: 1) "produce" or blend an alcohol mixture, or 2) sell or use for business 100% straight alcohol placed in the vehicle's fuel supply tank by the taxpayer. Because E95 fuel is composed of 95% ethanol and 5% denaturant, 95% of the 54¢ (or 51.3¢ per gallon of E95) per gallon tax credit can be taken. The tax credit effectively reduced the price of E95 to under 67¢ per gallon (or $1.12 per diesel equivalent gallon). ADM installed a 12,000-gallon ethanol fuel tank at the main truck terminal in Decatur. Because ADM was producing and refueling its own vehicles with ethanol, the company was eligible for the alcohol tax credit.

Weather/Terrain/Driving Conditions

Weather in central Illinois can be highly variable from day to day, as well as from season to season. Air temperatures can reach highs of +105°F in summer, and lows of down to -25°F in winter, with wind chills of as low as -60°F.

The terrain in Illinois is relatively flat and composed primarily of gently rolling farmland. Highway grades are generally less than 1 degree throughout most of the state. Every conceivable type of traffic situation, from high-speed interstate highways to heavily congested, stop-and-go urban streets, can be encountered in the state.

ADM Trucking, Inc., assigns each truck in its fleet to a specific driver and each driver uses the same truck every day. The five trucks used in this project were no exception—each was assigned to one driver. In this way, the driver becomes used to the vehicle and can usually determine when the vehicle is not running properly. Another feature of this is that different drivers operate their vehicles differently. In this case, the same driver will tend to operate the trucks in nearly the same manner every time. This allows us to identify any changes in fuel economy, repairs, and or maintenance.

Since the onset of the program, the four ethanol trucks and the one conventional diesel truck have been used to carry liquid CO_2 to soft drink manufacturers and other industrial users in the Midwest. Originally, it was planned that additional refueling sites be situated at ADM terminals in Iowa and Missouri to allow the trucks to travel interstate routes, but this would require major driver routing changes and was dropped from the project. Fully loaded, the GVW of each truck (including the diesel control truck) was about 55,000 pounds, making a direct fuel economy comparison possible. The trucks were all driven under the same climatic conditions to similar destinations. Because of the range of the ethanol trucks and the lack of E95 refueling facilities en route, each ethanol truck returned to the ADM plant in Decatur each night after being operated during the day. The conventional diesel control truck, ADM Unit #92010, was, when necessary, occasionally driven to overnight destinations because of its extended range and the ready availability of diesel fuel. Aside from this, operation of the five units was essentially identical.

Data Collection

One of the main purposes of this project was to collect data on fuel and oil usage, maintenance, repairs, and emissions for the four ethanol trucks. Similar data was also collected from the conventional diesel control truck. This data could then be used to compare and evaluate the performance and reliability of heavy-duty ethanol engines against conventional diesel engines, and to determine the costs of operating fleets of ethanol fuel trucks. This data has been sent to NREL for incorporation into the Alternative Fuels Data Center (AFDC).

There were three types of data collected from this program: (1) the repair and maintenance records collected by DDC (Figure 3), (2) hand-recorded fuel and oil usage information from ADM (Figure 4), and (3) computer-recorded data on maintenance and repair costs collected by ADM (Figure 5). The DDC records are in hard copy form. The ADM fuel and oil usage data was converted to a MicroSoft Excel spreadsheet file before being transmitted to the AFDC. The ADM maintenance and repair cost data was parsed before submission to NREL.

Program Promotion

The ethanol heavy-duty truck fleet demonstration program has been actively promoted by DCCA and the Illinois Corn Growers Association. It is important to remember that the four ethanol-powered trucks were part of a large, active fleet of heavy-duty delivery trucks and were intended

A-INTO SERVICE
B-ALT. FUELS COMPONENT FAILURE OR UPDATE
C-OTHER COMPONENT FAILURE
D-NON -ALT. FUEL COMPONENT UPDATE
E-MAINTENANCE OR MILEAGE UPDATE

ETHANOL TRUCK - ADM

VEH. #	UNIT #	MILES	DATE	TYPE	PART	PART MI	DESCRIPTION OF INCIDENT
92006	6VF-192394	4508	04/01/92	A			INITIAL WORK ON UNIT
92006	6VF-192394	4941	04/15/92	E			ECM REPROGRAM - CORRECT S/N & ROT.
92006	6VF-192394	19531	06/24/92	C	TURBO HOSE		BLOWN HOSE; AIR INLET HSG. ALIGNMENT
92006	6VF-192394	31165	08/12/92	C	SPRING PK.	31165	PREVENT. MAINT.- KNOWN PROBLEM WITH SPRING PK.
92006	6VF-192394	34199	08/26/92	B	F'DBACK POT	34199	LOW POWER-REPLACED FEEDBACK POT & PWM VALVE
92006	6VF-192394	34199	08/26/92	B	PWM VALVE	34199	LOW POWER-REPLACED FEEDBACK POT & PWM VALVE
92006	6VF-192394	43249	09/30/92	E			PUT SILICONE ON CAT. COV. TEMP. SENSOR
92006	6VF-192394	46754	10/14/92	E			#2R GLOW PLUG DEAD. REPAIRED WIRE TO TERMINAL
92006	6VF-192394	50563	10/29/92	E			MILEAGE UPDATE
92006	6VF-192394	50989	11/04/92	E			REPLACED VEHICLE SPEED SENSOR
92006	6VF-192394	59996	12/10/92	E			MILEAGE UPDATE
92006	6VF-192394	65651	01/07/93	E			PUT SILICONE ON CAT. COV. TEMP. SENSOR
92006	6VF-192394	71319	02/04/93	E			MILEAGE UPDATE
92006	6VF-192394	74052	02/19/93	B	INJECTOR	74052	HP DROPPING OFF; REPLACED ALL SIX INJECTORS
92006	6VF-192394	77555	03/04/93	E			CAT. CONV. TEMP. SENSOR - SEALED WITH RUBBER TAPE
92006	6VF-192394	79815	03/11/93	B	PWM VALVE	45616	NOT THROTTLE PROPERLY; STALLS - REPLACED PWM VALVE
92006	6VF-192394		04/06/93	B	BYPASS V'LV		J/B/ REPLACED BYPASS SOL. VALVE EARLIER IN WEEK
92006	6VF-192394	89002	04/22/93	E			INCREASED ROAD SPEED TO 69 MPH @ CUSTOMER REQUEST
92006	6VF-192394	90490	04/29/93	E			MILEAGE UPDATE
92006	6VF-192394	93955	05/14/93	E			MILEAGE UPDATE
92006	6VF-192394	102867	06/24/93	E			MILEAGE UPDATE
92006	6VF-192394	107696	07/13/93	E			MILEAGE UPDATE
92006	6VF-192394	112523	07/29/93	E			MILEAGE UPDATE
92006	6VF-192394	116857	08/16/93	E			MILEAGE UPDATE
92006	6VF-192394	119884	08/26/93	E			INSTALLED STARTER LOCK-OUT CONTROL RELAY

Figure 3. Sampling of Detroit Diesel Engine Data

10/93

	Initials	Date
Prepared By		
Approved By		

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92006

	Mileage	Fuel	Oil
10-1-93	129,001	103^{0}	
10-4-93	129,315	107^{0}	
10-5-93	129,585	79^{0}	
10-6-93	129,962	119^{0}	
10-7-93	130,255	91^{0}	
10-7-93	130,590	106^{0}	4 QTS
10-11-93	130,925	112^{0}	
10-12-93	131,268	106^{0}	
10-13-93	131,627	111^{0}	
10-15-93	131,963	109^{0}	
10-16-93	132,269	90^{0}	
10-18-93	132,576	96^{0}	
10-18-93	132,891	100^{0}	
10-20-93	133,254	104^{0}	
10-21-93	133,592	103^{0}	
10-21-93	133,917	109^{0}	
10-23-93	134,198	87^{0}	
10-26-93	134,578	94^{0}	
10-26-93	134,721	60^{0}	
10-28-93	135,063	101^{0}	
10-29-93	135,396	134^{0}	
10-29-93	135,703	103^{0}	
Starting	128,670		
Ending	135,703		
	7033	2224	4 QTS

Figure 4. ADM Manually Collected Truck Data

ADM HEAVY DUTY TRUCK DATA

TYPE	VEHICLE #	DATE	WORK ORDER #	MILAGE	COST	REASON CODE	DESCRIPTION	PT/REPAIR #	DESCRIPTION
L	92002	931112	RO41508	161315	0	38	WARRANTY	13	REPAIR
L	92002	931110	1111093	157599	2.24	5	DOT INSPECTION	30	FAST-LANE INSPECTION
L	92002	931109	RO24633	157599	70	8	PREVENTIVE MAINTENANCE	10	PM-AB
L	92002	931109	RO24633	157599	49	8	PREVENTIVE MAINTENANCE	10	PM-AB
L	92002	931109	RO24633	157599	42	8	PREVENTIVE MAINTENANCE	13	REPAIR
L	92002	931109	RO24633	157599	89.6	8	PREVENTIVE MAINTENANCE	13	REPAIR
L	92002	931109	RO24633	157599	28	8	PREVENTIVE MAINTENANCE	3	EXCHANGE - NEW
L	92002	931109	RO24633	157599	28	8	PREVENTIVE MAINTENANCE	3	EXCHANGE - NEW
P	92002	931109	RO24633	157599	30.94	8	PREVENTIVE MAINTENANCE	16008017	REAR SHOCK 92 TRACTORS
L	92002	931109	RO24633	157599	14	8	PREVENTIVE MAINTENANCE	3	EXCHANGE - NEW
L	92002	931109	RO24633	157599	42	8	PREVENTIVE MAINTENANCE	3	EXCHANGE - NEW
P	92002	931109	RO24633	157599	11.93	8	PREVENTIVE MAINTENANCE	31001059	BELT,ALT.92 ALCOHOL
P	92002	931109	RO24633	157599	3.5	8	PREVENTIVE MAINTENANCE	89000005	GAUGE,DEPTH TIRE TREAD
P	92002	931109	RO24633	157599	0.86	8	PREVENTIVE MAINTENANCE	89084153	"D" BATTERY
P	92002	931108	RO24633	157599	46.91	8	PREVENTIVE MAINTENANCE	44002055	FILTER,FUEL SECONDARY 92
P	92002	931108	RO24633	157599	68.86	8	PREVENTIVE MAINTENANCE	44002056	FILTER,FUEL PRIMARY 92
P	92002	931108	RO24633	157599	23.84	8	PREVENTIVE MAINTENANCE	45011061	FILTER,OIL 92 ETH TRCTR
P	92002	931108	RO24633	157599	2.28	8	PREVENTIVE MAINTENANCE	53999020	ANTIFREEZE
P	92002	931108	RO24633	157599	9.69	8	PREVENTIVE MAINTENANCE	53999035	OIL F/ETHNOLTRACTORS 92
P	92002	931108	RO24633	157599	7.96	8	PREVENTIVE MAINTENANCE	89128001	OIL SAMPLES W/POSTAGE
L	92002	931102	3110293	155472	9.24	5	DOT INSPECTION	30	FAST-LANE INSPECTION
L	92002	931102	3110293	155472	7	5	DOT INSPECTION	30	FAST-LANE INSPECTION
P	92002	931102	RO15098	155472	2.77	4	DRIVER REPORT	53999035	OIL F/ETHNOLTRACTORS 92
L	92004	931130	RO51631	101110	337.4	4	DRIVER REPORT	14	COMPLETE REBUILD
L	92004	931129	RO51631	101110	85.4	4	DRIVER REPORT	14	COMPLETE REBUILD
L	92004	931119	RO41867	101110	7	4	DRIVER REPORT	13	REPAIR
L	92004	931119	RO41867	101110	7	4	DRIVER REPORT	13	REPAIR
P	92004	931117	RO37717	101110	76.05	4	DRIVER REPORT	83011027	2" HOSE END CO2 KIT
P	92004	931117	RO37717	101110	5.49	4	DRIVER REPORT	83011036	2" COUPLER HVY WALL
P	92004	931117	RO37717	101110	3.64	4	DRIVER REPORT	83011057	2 TO 1 1/2 RDCR BUSHG
L	92004	931113	RO31782	100688	89.04	4	DRIVER REPORT	3	EXCHANGE - NEW
P	92004	931113	RO31782	100688	23.8	4	DRIVER REPORT	45011061	FILTER,OIL 92 ETH TRCTR
P	92004	931113	RO31782	100688	44.29	4	DRIVER REPORT	53999035	OIL F/ETHNOLTRACTORS 92

Figure 5. ADM Computer Maintenance and Repair Data

for day-to-day usage rather than as displays. Externally, the four trucks could be distinguished only by the "Ethanol 95" labels on each of the fuel tanks and by the circle of yellow corn kernels on either side of the hood.

The four ethanol trucks made numerous appearances at state and county fairs, ethanol rallies, parades, alternative fuel conferences, and other public events. General public interest in the ethanol trucks was very strong. One of the trucks was at the Ethanol Exposition at the Illinois State Fair each year for three straight years and remained a popular attraction. Displays about the project are still being used at the Expo.

Along with being prominently written up in the "Summary of Ethanol Projects in Illinois" updated bimonthly by DCCA staff, photographs and slides of the trucks have been shown and displayed at numerous meetings and conferences throughout the country. A paper entitled "The Ethanol Powered Heavy-Duty Truck Fleet Demonstration Project" (Appendix 2) was prepared and presented at the Tenth International Symposium on Alcohol Fuels in November 1993 in Colorado Springs, Colorado.

Fuel Economy: E95 versus Diesel

One gallon of #2 diesel fuel contains about 130,000 Btu of heat energy. On the other hand, E95 fuel contains 78,000 Btu per liquid gallon or about 60% of the energy of diesel fuel. Theoretically, the mileage and range of each of the four ethanol trucks should be about 60% of the conventional diesel control unit.

Originally, the diesel control unit, #92010, was getting slightly better than 6.0 miles per gallon over the first few months of the program. After this initial break-in period, the unit settled in at just over 5.8 miles per gallon with a range of between 5.0 and 6.6 miles per gallon. By comparison, the four ethanol trucks started out at about 3.2 miles per gallon, but gradually increased to an average of about 3.5 miles per gallon. A fuel economy of 3.5 miles per gallon of E95 is equal to 5.8 miles per diesel equivalent gallon. Therefore, the thermal efficiency of the ethanol engines was approximately the same as that of the diesel engine.

All five of the trucks exhibited slight seasonal differences in fuel mileage. Typically, mileages increased in the spring and fall, and decreased slightly in the summer and winter months. This is due, primarily, to the fact that diesel trucks are often left idling for extended periods of time in the winter in order to keep the engines warm and operating, and are run with air-conditioning turned on in the heat of summer. Aside from this, these were the only real variations encountered. Variations in seasonal fuel economy were less than 5% in most cases.

General Repairs and Maintenance

ADM Trucking operates its own general maintenance facility on site. DDC engineers and field service support staff held a training seminar for the ADM mechanics at the inception of the project.

The training included a new service manual on the ethanol engines, a review of the key components in the system, and a field troubleshooting course.

The drivers of the conventional diesel and four ethanol trucks all reported minor problems with their vehicles within the first few weeks of operation. None of these initial problems, however, were related to the engines or fuels used. The vast majority of problems were due to defects in the manufacture of the White-GMC tractors themselves. Loose and poorly fitted materials and panels inside the cab, which required minor, but time-consuming repairs, were frequently noted by the drivers.

Another complaint mentioned by all five drivers was with the 9-forward speed transmissions used in the trucks. The ratios between first and second gear, and second and third gear were reported to be too high to give good, smooth acceleration with a full load. The trucks would often "shudder" and lug in these lower gears.

The only scheduled maintenance for the ethanol trucks was oil changes. A special low-ash, petroleum-based oil with an ethanol-tolerant additive package (e.g., rust inhibitors and anti-foaming ingredients) was required and the oil in the ethanol trucks was to be changed every 6,000 miles. The oil in the diesel truck was also changed every 6,000 miles, as recommended by DDC. The cost of the oil used in each oil change on the ethanol trucks was $28.00, compared to $20.50 for the diesel control truck. ADM truck maintenance staff shipped a sample of the oil from each oil change to an independent laboratory for analysis. These analyses indicated if there were unusual amounts of metal present in the oil and acted as a key wear indicator.

Overview of Diesel Repairs

Essentially, the conventional 6V-92 diesel engine, ADM unit #92010, performed well throughout the test without the need for a major overhaul. This unit was in service three months longer than the ethanol trucks and the engine accumulated more than 400,000 miles with a good repair and maintenance record. The driver of unit #92010 was pleased with the overall performance of the tractor. This truck is still in service as of the writing of this report.

Overview of Ethanol Repairs

The original contract between DCCA (formerly ENR) and DDC called for two years of on-site engineering and field support for the four ethanol trucks. The DDC project engineer for most of the project was Mr. Jim Dyer. The field service technician support was provided by Clarke-Detroit Diesel-Allison from St. Louis, Missouri. In order to ensure that the program came to a successful conclusion, DCCA established and funded an additional technical service support contract with DDC (through Clarke) to cover the third and subsequent years of the project until its conclusion.

The following sections describe the major ethanol component failures encountered during the course of this project.

Fuel Injectors

Since the inception of the first alcohol (methanol) engines, the fuel injectors have a history of failure. Some of the first methanol buses in California experienced fuel injector failures in as little as 3,000 miles of usage. The EUIs on the ethanol engines were no exception and were the most troublesome component during this demonstration project.

The biggest problem encountered is that the injector tips become fouled and plugged with a gummy, black deposit that restricts fuel flow and interferes with the ability of the injector to atomize the fuel properly for complete combustion in the cylinder. The exact cause of the plugging and the exact composition of the black residue has still not been positively determined. It is believed that the deposit is, in fact, the upper cylinder lubricant, Lubrizol. One possible theory is that, as the engine cools during shutdown, the quick release of pressure on the fuel system, plus the heat of the engine itself, causes the residual fuel in the fuel injector tubes to boil, and the residue precipitates on the injector tips. This could explain why the fuel injectors in alcohol fuel urban transit buses, because they are started up and shut down much more often than the engines in over-the-road trucks, have even shorter life spans than the injectors in the trucks. DDC engineers are experimenting with check valves that fit in the injector fuel tubes that will slowly bleed off the pressure and minimize fuel boiling.

The effects of the plugging were noticed by the drivers, who reported low power and poor acceleration. Installation of a new set of injectors solved the problem each time and engine performance increased dramatically.

The first set of six fuel injectors on the four ethanol trucks were replaced at 63,471 miles on ADM unit #92008, with the last original set replaced at 87,203 on unit #92002. The injectors on unit #92004 were replaced at 79,361 miles and those on unit #92006 lasted 74,052 actual miles. After the initial injectors were replaced, injector wear prior to plugging was erratic. For example, the second set of injectors on #92002 was replaced at 179,823 miles (after 95,620 miles of service) while the second set of injectors on #92004 was replaced at 109,710 miles after 30,349 miles, and that set needed to be replaced again at 128,455 miles after only 18,745 miles had been accumulated. In all, 14 sets of fuel injectors were used in the four trucks during the course of the project. The average life of the fuel injectors was more than 60,000 miles prior to replacement, but this was highly variable from truck to truck and cannot be used as a definite projection of anticipated injector life. Fuel injectors on some of the early methanol buses in California were only getting about 3,000 miles of service before they needed to be replaced. Even now, injectors on ethanol and methanol buses using the 6V-92 engine are, at best, accumulating about 30,000 to 35,000 miles between replacements. This project showed much better injector life than on the transit buses, probably due to the duty cycle of the trucks. At almost $1,000 per set of injectors, however, this became a major expenditure for the ethanol trucks. Fuel injector plugging is the one significant problem that still remains unsolved when evaluating the viability of ethanol- and methanol-powered heavy-duty engines.

One of the new products developed by DDC as a result of this program was the titanium plunger fuel injector, which has become standard on all DDC engines. Ethanol and methanol both lack the lubricating qualities of diesel fuel (also referred to as the "lubricity" of the fuel) and are called "dry" fuels. The lack of lubrication in the fuel can create excessive wear on fuel system parts such as the plungers in fuel injectors. The idea behind the new injectors developed as a result of this project was to eliminate this wear by using a very hard metal like titanium in the injector plungers. The new titanium plunger injectors have proven highly durable in both DDC's ethanol and conventional diesel engines.

Cylinder Heads

A broken intake valve in the cylinder head caused one major breakdown on unit #92006. DDC field support staff found that the valve had been sticking, which allowed hot exhaust gases to get behind the valve and burn out the valve seat. The entire cylinder head was sent back to Detroit for analysis and it was determined that a slight defect in the head itself caused the problem. A new cylinder head and valves were installed on the truck and there were no further incidents.

Glow Plugs

Another complaint from the ethanol truck drivers was the one-minute delay necessary for the glow plugs to heat the upper cylinders of the engine prior to start up. DDC has been working on the development of ceramic glow plugs that would allow the delay time to be reduced to 15 or 20 seconds instead of one minute.

Each of the four ethanol engines was equipped with a set of six glow plugs that was used to assist starting of the engine. The glow plugs were turned on for one minute to heat the upper cylinder prior to starting the engine, and remained on until the engine coolant reached normal operating temperature. Occasionally, one of the glow plugs would burn out or one of the tips would break off, causing engine starting problems. These failures were relatively infrequent. In all, 11 glow plugs were replaced during the course of this project.

Bearings

The ethanol engine in ADM unit #92004 required a major overhaul during the course of the project. Oil samples taken in October and November 1994 indicated high concentrations of lead and copper particles. This was correctly interpreted as bearing wear on the engine. In December 1994, at 109,710 miles, the engine from unit #92004 was partially torn down and examined. It was determined that the rod and main bearings and thrust washers were badly worn. New bearings, as well as new cylinder kits, were installed and the truck was operational within a few days. Jim Dyer, the DDC project engineer, decided at that time that the cause of this unusual wear was directly related to the internal cylinder pressure causing undue stress on the bearings. Because of the higher compression ratio of the ethanol engine and the increase in the amount of fuel being combusted in the cylinder, the fuel was beginning to combust while the piston was relatively far away from the its full upstroke into the cylinder. Because the combusting fuel was generating high- pressure gas so early, the pistons, rods, and bearings were being subjected to high pressure on most of the piston upstroke as well as on the downstroke side. In order to reduce the cylinder pressure, Mr. Dyer altered the engine timing from 23° BTDC (before top dead center) to 12° BTDC. This timing modification appears to have eliminated the problem. As a result, the remaining three ethanol trucks, as well as *all* other Detroit Diesel 6V-92TA ethanol engines currently in service, have been altered to 12° BTDC.

Other Components

The only other major ethanol fuel system components that were troublesome were the fuel pumps. Three of the pumps were found to be "noisy" and were either replaced or the motor front bearings were replaced.

The balance of the repairs to the four ethanol trucks were primarily electronic in nature. Several PWMs (pulse width modulators) were replaced on each of the units as were several switches, solenoids, and sensors. The malfunctioning PMWs caused erratic engine idling.

Comparison of Diesel and Ethanol Repairs

The maintenance and repair data supplied by ADM have been closely examined. This information contains primarily normal preventive work on all five of the units. Items such as nuts and bolts, light bulbs, windshield wiper blades and solvent, tire work, antifreeze, accident reports and repairs, and fast-lane inspections are included in the data. Essentially, there were no significant differences in *general preventive maintenance costs* noted between the ethanol trucks and the diesel control truck based on this information. Additionally, the only significant specific preventive repair and maintenance cost differences were incurred on the special oil and oil filters used on the ethanol trucks.

The information collected by the Detroit Diesel Corporation field service people provided the most useful data on the project. Based on this data, it appears as though the ethanol trucks were as reliable and on the road about the same amount of time as the diesel unit. There were periods, of course, where the ethanol trucks were out of service for relatively long periods of time because, unlike diesel trucks where there are numerous repair facilities, the Clarke-Detroit Diesel-Allison field service technicians had to drive up to the site from their facility in St. Louis to perform repairs. Additionally, the ethanol-related replacement parts were not always immediately available and had to be shipped in from Detroit.

Ethanol Emissions Data

The four ethanol engines used in this project were all prototypes, produced before the DDC 6V-92TA ethanol engine was available as a production engine. The ethanol engines were produced in February 1992 and later programmed through the DDEC II unit with the data generated from the engine certification tests.

The original transient emissions tests were performed at Southwest Research Institute (SwRI) of San Antonio, Texas, on a representative prototype 6V-92TA ethanol engine in April and May 1992. The results for these tests are displayed in Figure 6. These results clearly indicated that the ethanol engine surpassed the established 1994 U.S. EPA emissions standards for heavy-duty engines of this type.

While the ethanol trucks and the diesel control unit were in active service, it was determined that the emissions from these vehicles needed to be monitored periodically. For this reason, an agreement was made to have the emissions checked annually by the U.S. Department of Energy/West Virginia University Transportable Emissions Testing Laboratory. The West Virginia lab was performing annual emissions tests on several of the ethanol buses in Peoria, so it was decided to test one or two of the ethanol trucks, along with the control diesel unit, at the same time. The trucks were tested four times during the course of the project.

The results of the first series of emissions tests WVU performed on the ethanol trucks are not representative of the trucks' in-use emissions. The transportable lab was relatively new at this time and not all of the "bugs" had been worked out. The original driving cycle used to test the trucks was the same duty cycle as the one used for transit buses. Transit buses are equipped with automatic transmissions because of the stop-and-go driving situations they encounter every day. The duty cycle being used by WVU required a full open-throttle acceleration to 25 miles per hour in under ten seconds, followed by several seconds of sustained 25 mile per hour driving, then brake and decelerate to zero. This type of cycle was practically impossible for the trucks to follow because of their 9-speed manual transmissions. It is unlikely that a truck, especially with any substantial load, could attain a speed of 25 miles per hour without having to change gears at least twice in the process. Because of this, the test cycle was modified in subsequent tests.

WVU made a concerted effort to change the duty cycles and improve the results of their tests on each of the next three series of emissions tests. Data from the second and subsequent series of emission test results are contained in Appendix 3. In summary, the tests indicated that particulate matter (PM) and NO_x emissions were lower than those from the diesel truck, but that emissions of HC and CO were significantly higher than those from the conventional diesel control truck. This is exactly opposite of what was anticipated based on the original transient emissions tests performed by DDC.

WVU has conducted numerous emissions tests on heavy-duty vehicles being operated on alternative fuels throughout the country. Briefly, the results of these tests indicate that ethanol buses emit PM levels similar to those of conventional diesel engines equipped with particulate traps and much lower than diesel engines without these particulate traps. Further, the work by WVU also indicates that ethanol engines tend to emit marginally lower levels of NO_x than their diesel counterparts, but emit higher levels (on average) of CO and HC than the diesel engines.

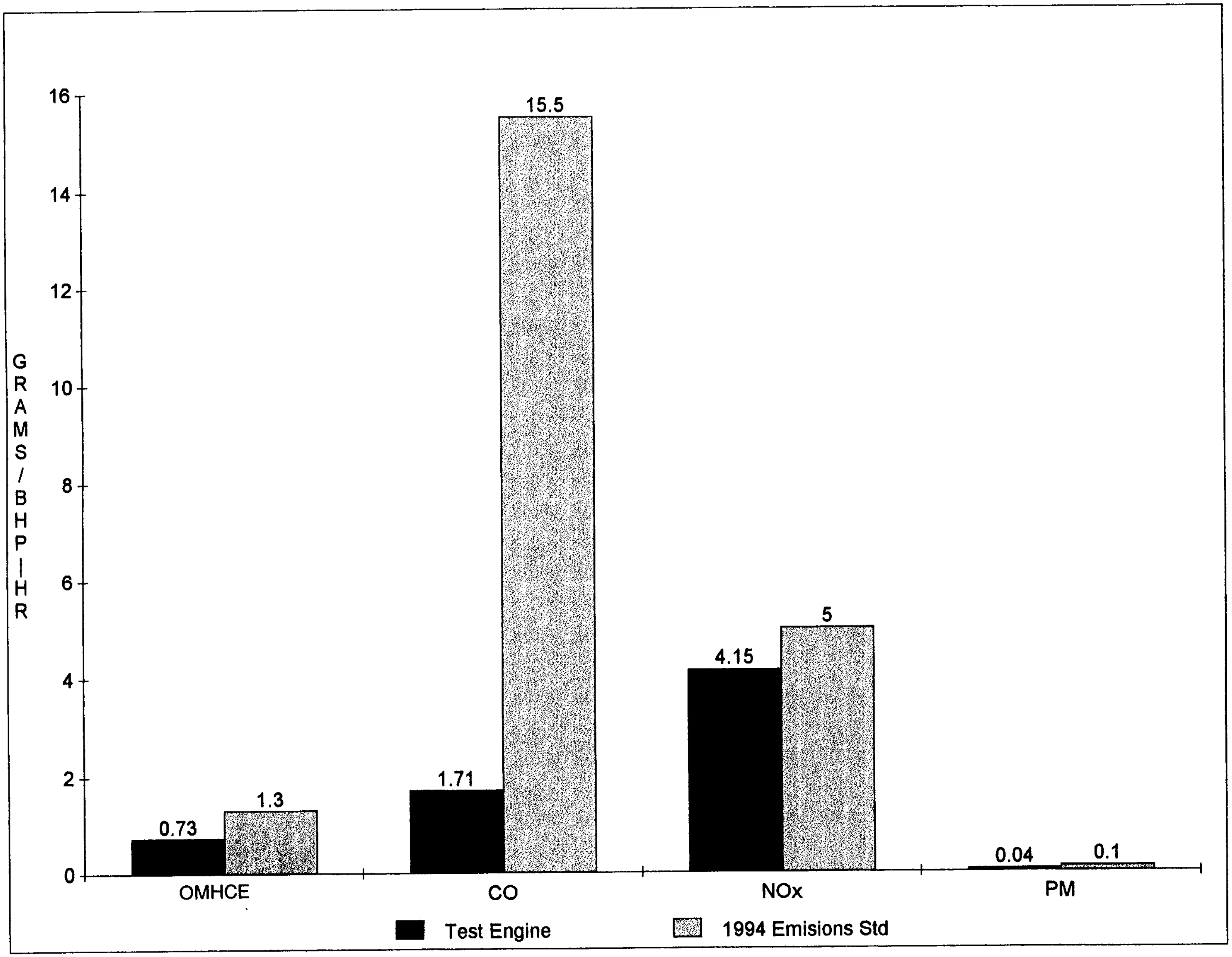

Figure 6. Ethanol 6V-92TA Engine Certification Data

In March 1996, the ethanol engine was removed from ADM unit #92002 and shipped toSwRI in April 1996 for emissions testing. The original contract called for the ethanol engine to be at DDC, but was tested at SwRI because of availability problems with emissions test cells at DDC. The ethanol engine, serial number 6VF192482, in unit #92002 had accumulated more than 325,000 miles without the engine needing to be rebuilt. However, a problem had occurred with this engine only a few weeks before it was to be removed, causing some hesitation about testing it. As it turned out, the repair was minor. Inspection of the engine revealed the tip of a glow plug had broken and a piece of the glow plug was wedged beneath the exhaust valve. Fortunately, the piston and cylinder liner components were undamaged. This problem was corrected by replacing the glow plug and exhaust valve. Aside from this, the unit had been operating satisfactorily.

The emissions testing procedures used by SwRI were identical to the original engine certification tests. Measurements were conducted in general accord with the procedure for testing methanol-fueled engines specified in the EPA standards, 40 CFR 86 Subpart N, with provisions developed by the SwRI project leader and previously applied to an engine operating on ethanol in SwRI Projects 08-4883 and 08-5986, conducted for Detroit Diesel in 1992 and 1993. One cold-start and two hot-start transient emissions tests were conducted with the original catalytic converter and with a replacement catalyst (the replacement catalyst had accumulated about 5,000 miles of service). These tests included analyses for ethanol and aldehydes. Additionally, one hot-start test, exclusively for ethanol and aldehydes, was performed without the catalyst.

The emissions test results are summarized in Figures 7, 8, and 9. The gaseous and particulate emissions instrumentation and procedures were conducted in accord with 40 CFR Part 86. HC emission levels are measured continuously during each mode or cycle by heated flame ionization detector (FID). CO and CO_2 emissions are measured by non-dispersive infrared (NDIR) using bagged samples. NO_x emissions are measured continuously by heated chemiluminescence (CL).

In brief, the emission results show very good numbers for the levels of NO_x and PM. The numbers obtained are quite close to the original certification values shown in Figures 7, 8, and 9. As found in the chassis dynamometer testing, the HC and CO emissions, however, are high with both catalysts and it was believed that this was due to the plugging problem with the ethanol fuel injectors described earlier in this report. The fuel injectors on this particular engine had accumulated 145,000 miles. DDC's analysis revealed that the injector "pop" pressures were at 2,800 psi, which is approximately 38% below the design "pop" pressure of 4,500 psi. Further, the injectors failed to properly atomize the fuel. It is also quite evident in Figure 8 that the new catalyst significantly improved HC and CO emissions, indicating that the old catalyst was nearing the end of its useful life.

When the emissions tests were complete, the engine was taken to Stewart & Stevenson, Inc. , of San Antonio, a DDC Distributor, for disassembly and inspection under the supervision of Mr. Jim Dyer of Detroit Diesel Corporation.

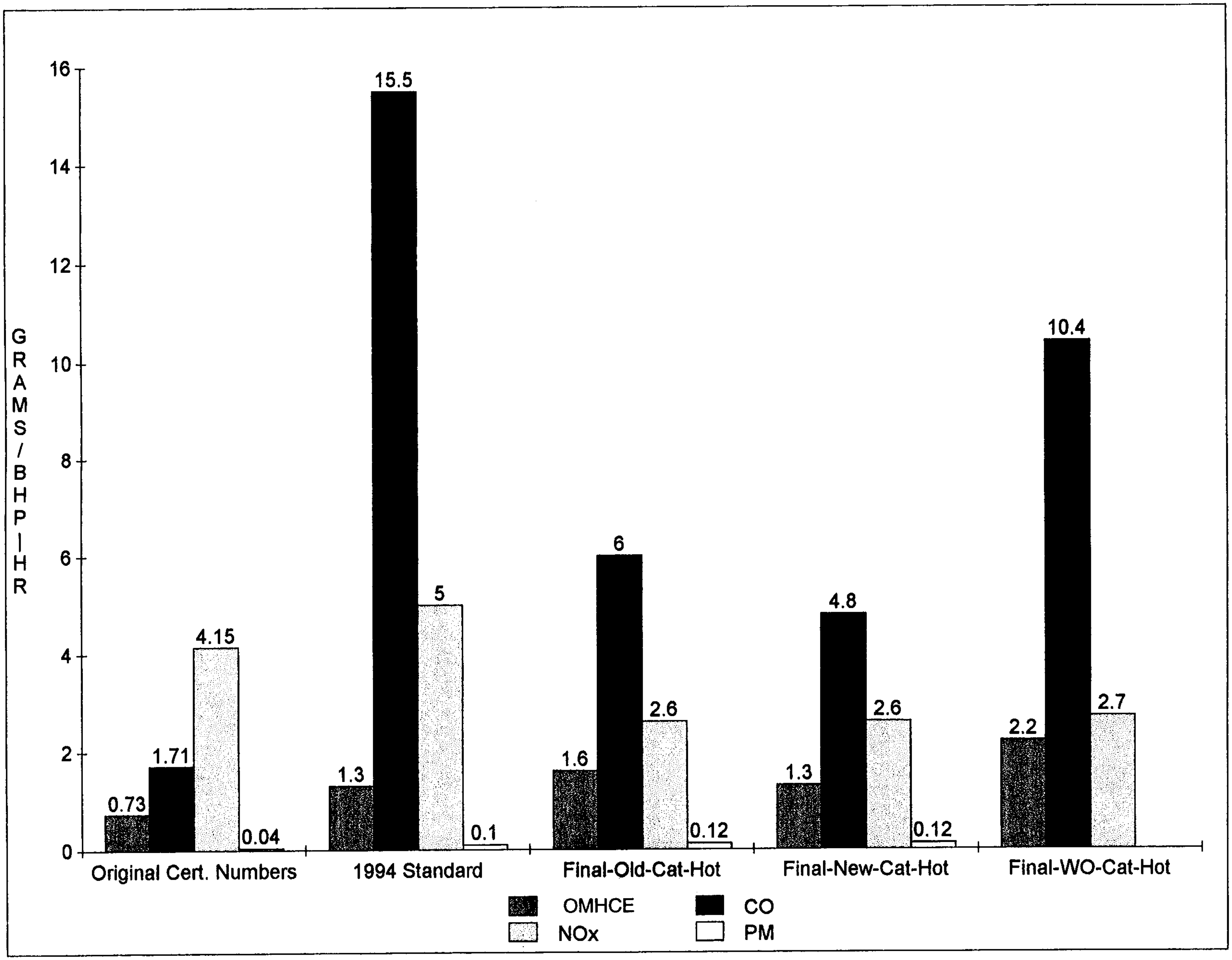

Figure 7. Final Emissions Data (Hot Engine)

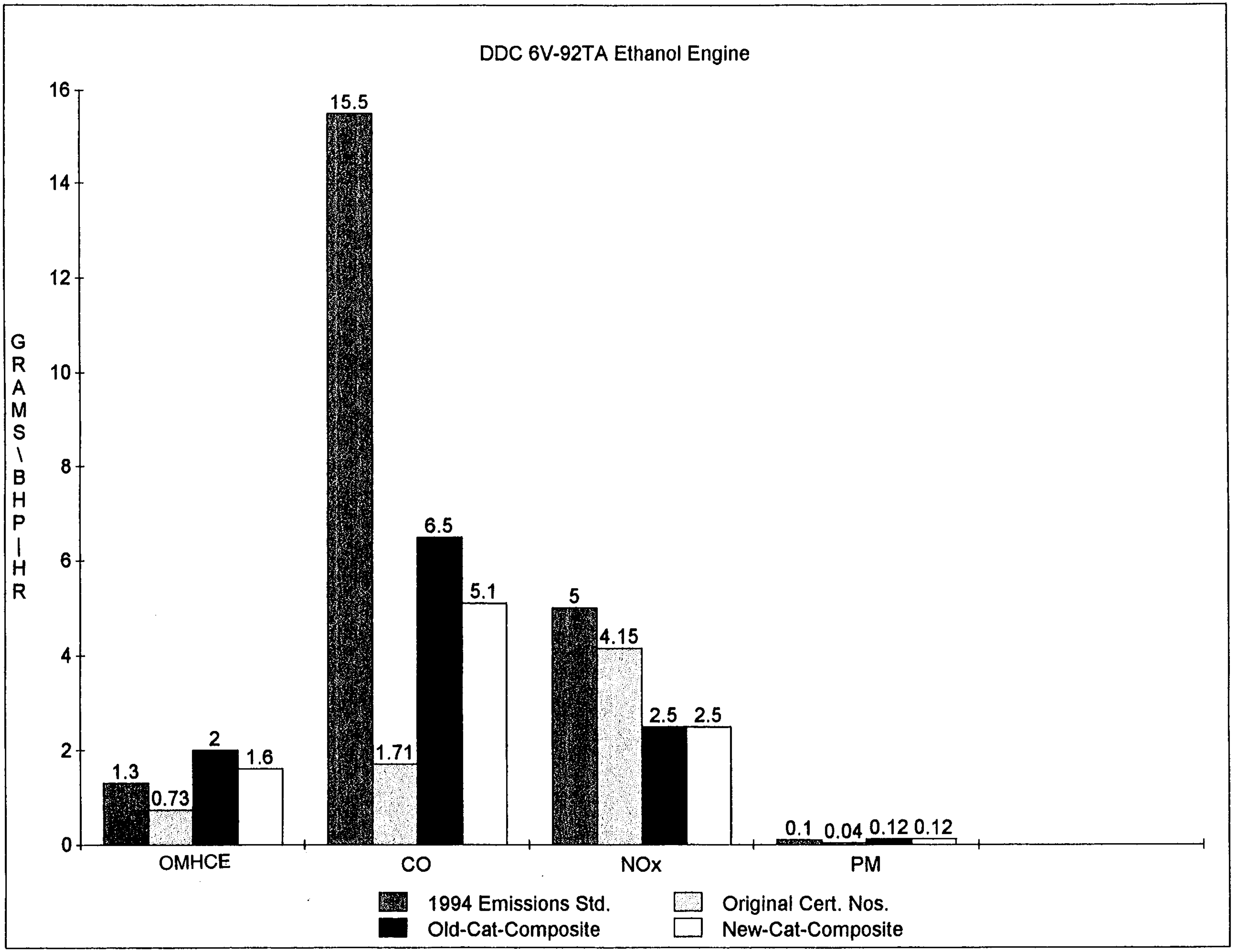

Figure 8. Final Emissions Data (Composite)

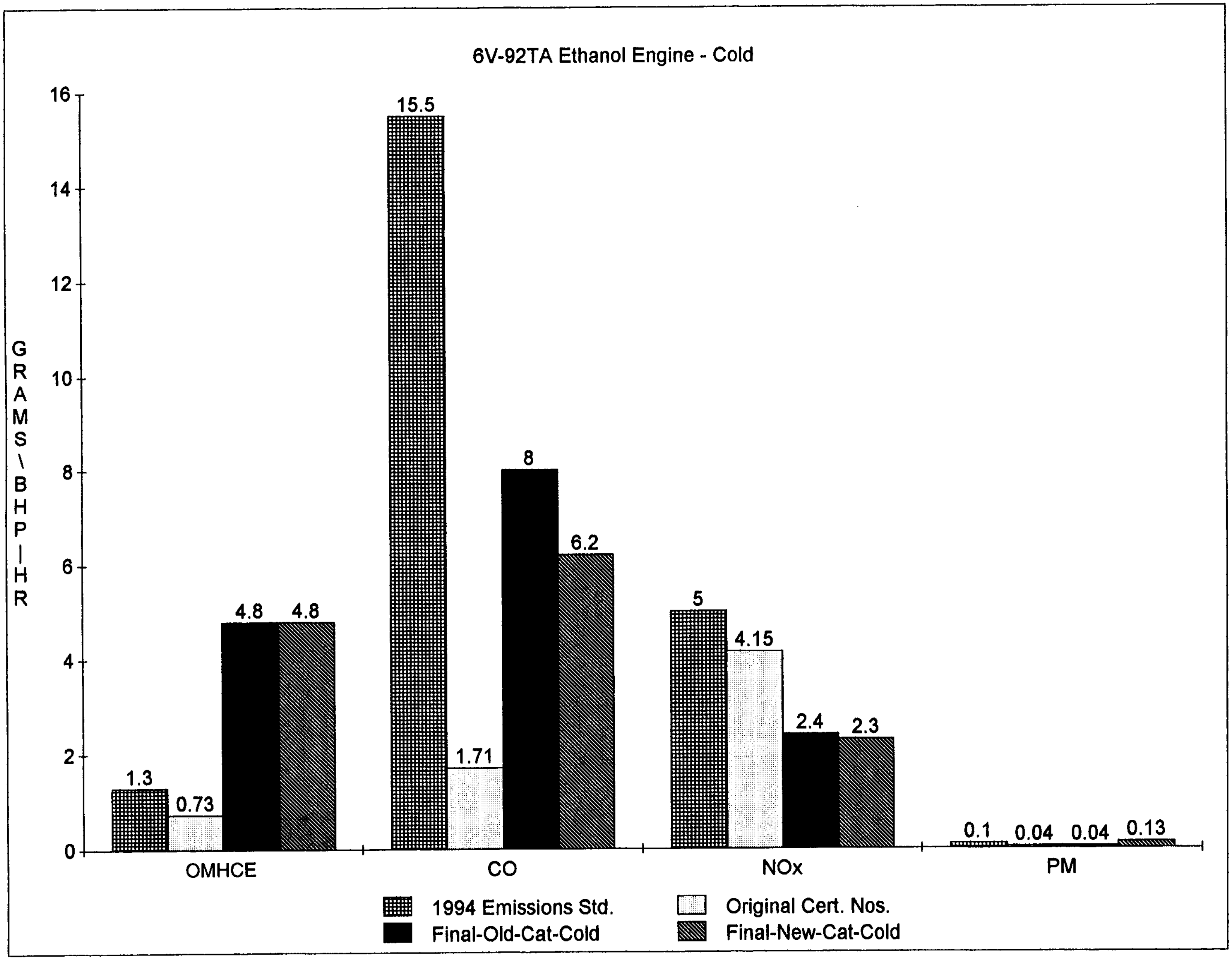

Figure 9. Final Emissions Data (Cold Engine)

Ethanol Engine Wear

The following are key components of the ethanol engine that were critically examined for wear:

Crankshaft, Main Bearings, and Rod Bearings

The visual inspection showed that the crankshaft was in excellent condition with no sign of distress. The crankshaft was also found to be in good condition with only a small amount of copper showing on one of the main bearings. All of the upper rod bearings had some minor wear with moderate amounts of copper showing, which indicates normal wear for this amount of mileage with a 23:1compression ratio. No leaks were found on the rear crankshaft seal but slight leakage was found on the front crankshaft seal.

Cylinder Kits

The general condition of the cylinder liners, piston domes and skirts, and piston rings was also excellent. Only minor wear showed on any of the parts. The piston rings were removed and shipped back to DDC in Detroit to determine chrome thicknesses. The amount of chrome specification on new fire rings and compression rings is between 0.07 inches and 0.09 inches. The average amounts of chrome on the fire rings and compression rings from the worn ethanol engine in this case were 0.0626 inches and 0.0553 inches, respectively, showing very little wear.

Piston heads, rods, bushings and bushing pins were all in good condition with wear patterns typical of an engine with this number of miles.

Cylinder Heads

The rocker arms and overhead assemblies were in good condition with no signs of distress. There were also no indications of any fuel leaks from the injectors.

The right cylinder bank was removed, inspected, and found to be in good condition with no signs of distress. The left bank cylinder was found to have a valve-to-valve crack, but there were no indications of a coolant leak. There was also evidence of a blown compression seal between two of the cylinders as indicated by slight discoloration on both upper cylinder sleeves.

Visual inspection of the exhaust valves indicated that a small amount of engine oil was passing between the valve stems and valve guides, typical of an engine with this number of miles.

Camshafts and Gear Train

The camshafts were in excellent condition with no visible flat spots or pitting. The gear train was also in excellent condition with no apparent signs of wear.

Economic Comparison

Figure 10 represents a breakdown of the costs associated with owning and operating a fleet of heavy-duty, over-the-road trucks. Please note that the Driver Wages, Licensing, Permitting, and Insurance, Profit, Management, and Miscellaneous category costs in this project are essentially identical costs for both the ethanol and diesel trucks and are not directly related to the economic comparison being made here. *However, it should also be noted that the initial installed cost of each of the ethanol 6V-92TA engines was $31,500, about twice the cost of the conventional diesel engine.*

According to Figure 10, the average costs of fuel and maintenance account for about 29% of the total operational costs. Aside from the higher initial cost of the ethanol engines, these two cost areas

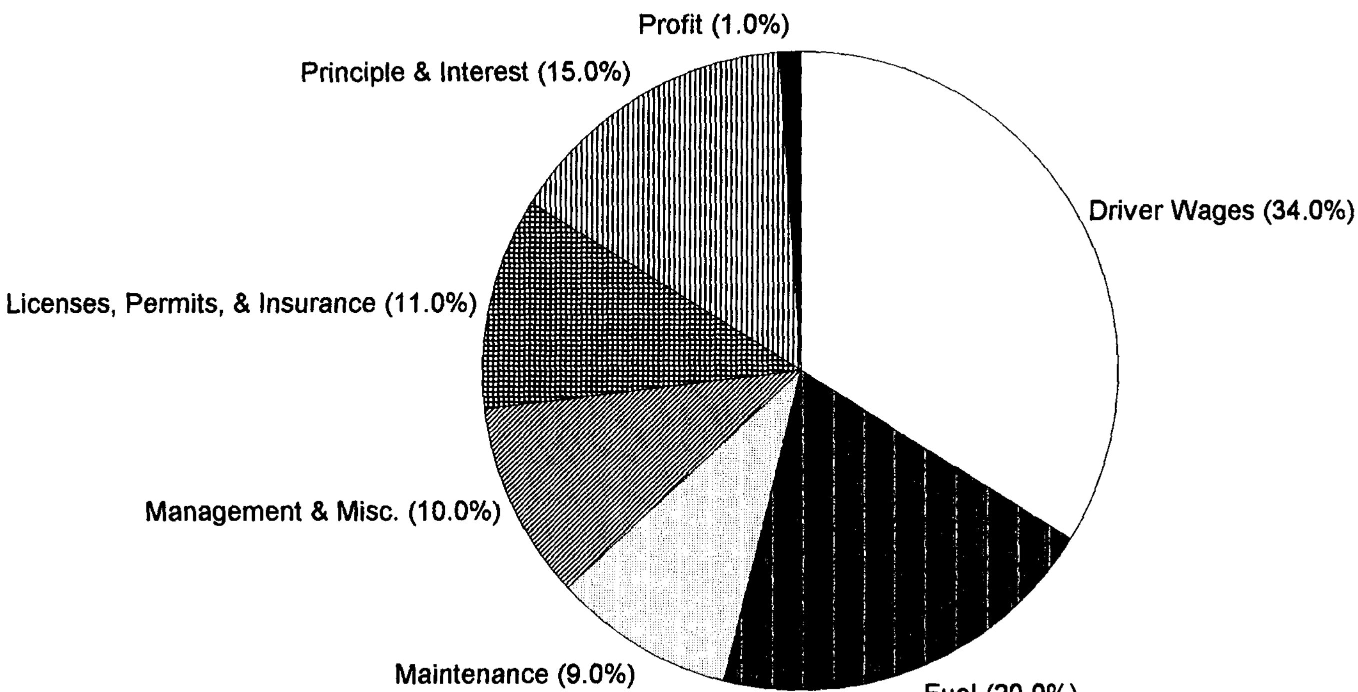

Figure 10. Fleet Operational Costs

are the main variables when comparing the economics of a fleet of ethanol trucks with a fleet of diesel trucks.

Fuel economy and costs of operation were two of the critical categories of data collection in this project. As previously mentioned, E95 contains about 60% of the Btu content of an equivalent volume of diesel fuel. It has also been established that the cost of E95 fuel averaged about $0.67 per gallon (after the alcohol tax credit was applied to the fuel formulation) compared to an average of $1.08 per gallon for diesel fuel. These figures will be used in all of the economic data presented here.

During the first three months of the project, the four ethanol trucks averaged 3.2 miles per gallon with a range of between 2.9 and 3.5 miles per gallon. By comparison, the diesel truck averaged almost 6.0 miles per gallon during the same three-month period of time. The ethanol engines seemed to break in after a short amount of time and the average mileage settled in at 3.2 miles per gallon while the diesel settled in at 5.8 miles per gallon. As previously described, the average cost was $1.08 per gallon for diesel fuel and $0.67 per gallon for ethanol during the course of this project. Using these fuel cost figures, fuel cost for the the ethanol trucks averaged 19.1¢ per mile versus 18.6¢ per mile for the diesel trucks. Over 300,000 miles, the net fuel cost difference would be $1,500 more to operate an ethanol truck than a conventional diesel truck.

From the ADM maintenance and repair data, the only significant difference between the ethanol truck and the diesel truck *preventive* maintenance and repair costs was the cost of the special ethanol-tolerant motor oil used and the oil and fuel filters used on the four trucks. (note that the ADM repair data do not reflect the costs of glow plugs, fuel injectors, and other ethanol fuel system parts covered under the field service contract.) As previously mentioned, oil for the ethanol trucks was $28.00 per oil change compared to $20.50 for the conventional diesel. Oil filters for the ethanol trucks were $35.62, compared to $8.48 for the diesel unit. Fuel filters (primary and secondary) on the ethanol trucks were $48.34, compared to $6.30 on the diesel. Therefore, the cost of an oil change and filter on the ethanol trucks was $34.64 more expensive than on the diesel, and the fuel filters were $42.04 more each time they were changed. All other repair, maintenance, and U.S. Department of Transportation inspection costs are considered normal fleet wear-and-tear items that are incurred on any truck, regardless of fuel type.

Taking all of these items into account (see Figure 11) over 300,000 miles (three years at 100,000 miles per year), additional costs of operation for each of the ethanol trucks would be $1,500 for fuel, $1,732 for oil changes (one oil change every 6,000 miles times an additional $34.64 per oil change), $252 for six fuel fuel filter changes at 50,000 miles each, and $5,000 for additional electronic fuel injectors based on 60,000 miles of usable injector life and $1,000 per set of six injectors. The total additional costs per ethanol truck, then, would be $8,484 per 300,000 miles or $2,828 per 100,000 miles of service. Once again, it should be noted that these figures do not reflect other costs such as glow plugs and fuel injectors, or the costs of the DDC field service support.

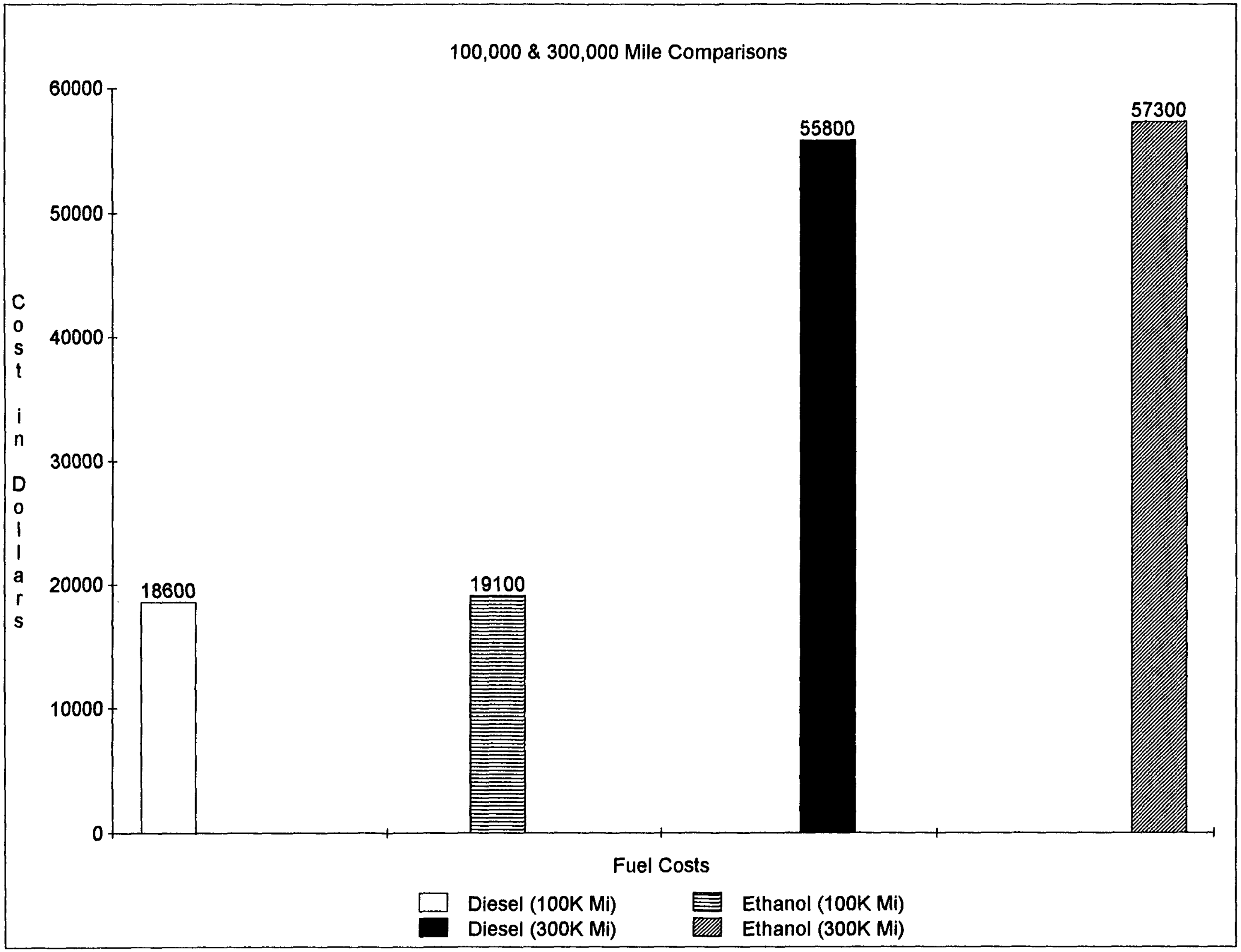

Figure 11(a). Fuel Costs

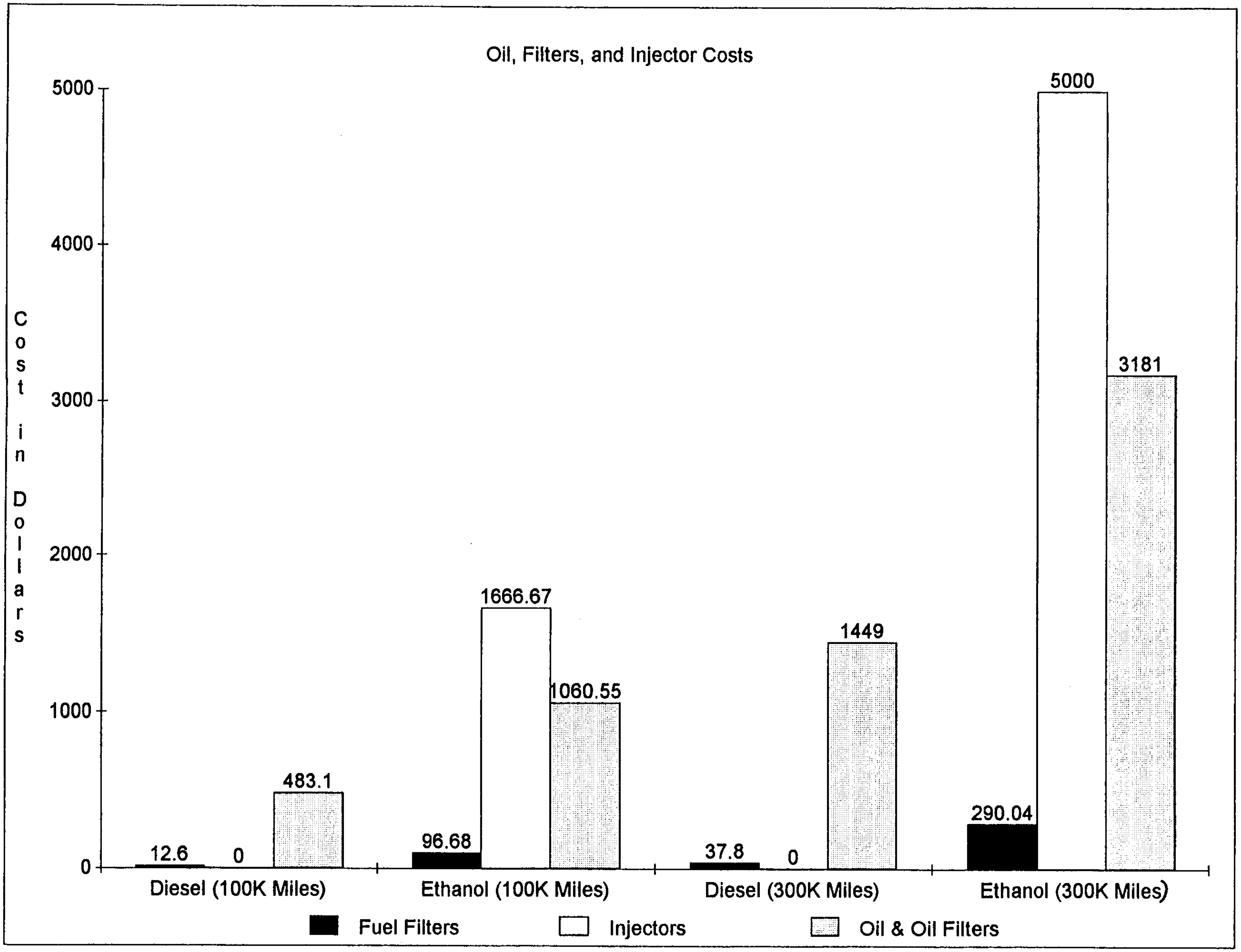

Figure 11(b). Oil, Filter, and Injector Costs

As with any vehicle, unforeseen factors can change operating costs in any fleet. Individual driving habits can have a direct bearing on critical factors such as fuel economy and wear and tear on the vehicle.

Overall Project Evaluation

Representatives of the AE Section of the Illinois DCCA have been very pleased with the results obtained from this project. They have concluded that the ethanol trucks are comparable to diesel trucks in terms of durability and in the costs of maintenance and repairs. Operational costs, related to the higher original cost of the 6V-92TA ethanol engine, the higher price of E95 ethanol fuel (without the alcohol tax credit), special ethanol components such as the high flow capacity fuel injectors, and the low mileage because of the lower energy content of the fuel, are, without question, higher than those of conventional diesel engines.

The ADM managers and drivers responsible for operation of this project were all highly cooperative. The general consensus was that the four ethanol trucks were as reliable and performed as well as their conventional diesel counterparts throughout the course of the project. Of course, being a business, ADM Trucking recognized the obvious disadvantages of higher fuel costs, the limited operating range of the vehicles (because an established E95 refueling infrastructure is lacking), higher costs on certain general maintenance items such as fuel filters and oil changes, the limited life and high replacement costs of the electronic fuel injectors as well as other ethanol-related components, and the need for field service support from DDC, the engine manufacturer.

The DDC field support and engineering staff was very cooperative and helpful in trying to resolve any of the problems that arose during the project. The DDC staff was also pleased with the overall performance of the 6V-92TA ethanol engines in the trucks. A lot of the development work on the methanol version of the engine paved the way for this relatively smooth ethanol fleet demonstration. The ethanol fleet project also produced several new engine components (including the titanium plunger fuel injectors) that are now standard equipment on all of DDC's current production diesel engines.

Conclusions and Discussion

This project can be considered a success in many ways. First, a heavy-duty, ethanol-powered engine was developed and emissions-certified for use in urban transit buses and over-the-road trucks. To date, the DDC 6V-92TA is the only alcohol fuel engine that can make this claim. Secondly, it has proven that an ethanol engine could perform as well as a conventional diesel engine under the demanding conditions of heavy-duty vehicle fleet operations. The drivers of the trucks could not find a difference in horsepower or overall performance between the ethanol engine and the diesel engine. Third, it was shown that the ethanol-fueled engines were as durable and reliable as their diesel counterpart. The actual miles accumulated on the ethanol trucks, especially ADM unit #92002, which reached 325,000 total miles without a major overhaul, are comparable to the miles accumulated on a 6V-92 diesel engine prior to its first overhaul. Finally, it showed that the ethanol heavy-duty engine was capable of meeting the new stringent emissions standards.

As with any other "first of its kind" demonstration project, problems were encountered. The first problem was the matter of fuel injectors, which had a pronounced tendency to become partially or almost completely plugged with a black, gummy substance (of uncertain composition and origin), limiting their ability to provide adequate fuel to the cylinders. This partial fuel injector plugging may also have a direct effect on engine emissions, as suggested by the results of final transient emission test data. This significant problem needs to be resolved if alcohol fuels are to become viable alternative transportation fuels.

The second problem is the lack of a refueling infrastructure, which limited the distance the trucks could be driven. Additionally, because of lower energy content per unit volume of ethanol as compared to diesel fuel, the range of the ethanol vehicles was severely limited.

The third and most critical issue is the costs associated with operating a fleet of ethanol-powered vehicles. Although costs of operation for the ADM ethanol fleet were higher than costs for diesel vehicle fleets, the application of the alcohol tax credit to the E95 fuel allowed the differential costs to be minimal. The alcohol tax credit is due to sunset in the year 2000. Unless ethanol production costs and, therefore, the cost of ethanol fuel can remain competitive with conventional fossil fuel on a price per Btu basis, the viability of ethanol as an alternative transportation fuel is uncertain.

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Marek, Norman J., "Application of the Alcohol Fuels Credit to Hydrated Ethanol Transportation Fuels." Springfield, Illinois: Illinois Department of Commerce and Community Affairs. 1995.

Special Note: For additional information, please contact the following:

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Springfield, Illinois 62704
(217) 785-2800

The National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401
(303) 275-4424

or visit the AFDC at:

http://www.afdc.nrel.gov

Appendix 1

Application of the Alcohol Fuels Credit to Ethanol-Based Alternative Transportation Fuels

Note: This paper was originally published by the Illinois Department of Commerce and Community Affairs, Springfield, Illinois, 1994.

APPLICATION OF THE ALCOHOL FUELS CREDIT TO ETHANOL-BASED ALTERNATIVE TRANSPORTATION FUELS

by: Norman J. Marek, Program Manager
Alternative Transportation Fuels
Illinois Dept. of Energy & Natural Resources

Gregory W. Lawler, Tax Accountant
GROWMARK, Inc.

Background:

The State of Illinois, through the Illinois Department of Energy and Natural Resources, has been actively testing and demonstrating the use of high percentage blends of ethanol fuel as a substitute for gasoline and diesel fuel. Currently operating in Illinois are over 100 E-85 ethanol cars, 14 E-93 ethanol powered transit buses in Peoria, and 4 E-95 heavy-duty, over-the-road trucks operated by Archer Daniels Midland (ADM) in Decatur.

GROWMARK, Inc., a regional farm cooperative based in Bloomington, Illinois, has supplied E-85 fuel for state vehicles since July 1992. Recently, GROWMARK, along with Pekin Energy Company of Pekin, Illinois, has been supplying ethanol fuel for the Peoria transit buses. ADM has been using E-95 ethanol fuel they produce for their heavy-duty trucks based in Decatur, Illinois.

Vehicles using ethanol-based fuels get fewer miles per gallon than gasoline or diesel vehicles since ethanol fuels have about two-thirds of the energy content of their fossil fuel counterparts. Ethanol fuels are also more expensive. In March 1994, the central Illinois market price of denatured ethanol was \$1.08 per gallon, compared to \$0.48 and \$0.56 per gallon (before taxes) for gasoline and diesel fuel. These two factors result in higher operational costs for ethanol vehicles. However, using the federal income tax credit for alcohol used as fuel can significantly lower the fuel cost (and operational costs) to the end user.

The Alcohol Fuels Credit:

Congress developed the alcohol fuels credit in response to the energy crisis of the late 1970's and early 1980's. The intent was to foster growth of the alcohol industry by subsidizing non-petroleum based alcohol used as fuel so the cost for the end user would be comparable to traditional hydrocarbon fuels. This subsidy is accomplished in two ways:

- by granting a 5.4¢ per gallon partial excise tax exemption for 10% alcohol blended fuels (gasohol), and
- by allowing a 54¢ per gallon income tax credit for ethanol used as a fuel.

The income tax credit is available to *taxpayers* who:

- "produce" or blend an alcohol mixture, or
- sell or use for business 100% straight alcohol actually placed in the vehicle's fuel supply tank by the taxpayer.

A governmental unit like the State of Illinois or the Peoria Mass Transit District cannot utilize an income tax credit since they are not subject to income taxes. To benefit from the credit, they must use an alcohol mixture purchased from a fuel blender or have a fuel dealer fill vehicles with straight alcohol. Further, the blender or dealer must be subject to income taxes, have sufficient income tax liabilities to make use of the credit, and be willing to pass through the value of the credit by selling the fuel at a reduced price.

E-85 Ethanol Fuel:

By law, ethanol must contain 2% to 5% denaturant (poison) to avoid taxation as consumable alcohol. The E-85 fuel used in the light-duty passenger vehicles is composed of 85% denatured ethanol and 15% light hydrocarbons (to ensure quick starting). The Chevrolet Motor Division of General Motors determined the 5% denaturant used by ADM, called "natural" gasoline (composed primarily of C4-C5 hydrocarbons), was also acceptable for the 15% light hydrocarbon fraction of the fuel. Therefore, final composition of the fuel is approximately 81% anhydrous ethanol and 19% natural gasoline. This formulation is seasonally adjusted to 70% ethanol / 30% natural gasoline to ensure starting during cold weather.

E-95 Fuel Versus E-93 Fuel:

The original E-95 fuel is composed of 95% anhydrous ethanol and 5% hydrocarbon denaturant. This fuel is also called "neat" ethanol and can be blended directly with gasoline to create the 10% ethanol blends commonly used in passenger vehicles. The E-95 fuel used initially in the Peoria buses contained 5% unleaded gasoline denaturant. This is considered 100% straight ethanol and only the taxpayer placing the fuel in the vehicle may claim the tax credit.

The Peoria buses now use an E-93 fuel formulation consisting of 93% anhydrous ethanol, 2% #1 kerosene denaturant, and 5% synthetic (made from natural gas or coal) methanol. Detroit Diesel Corporation (DDC), the manufacturer of the bus engines, approved this blend and warranties engines using it. (DDC engineers believe the new E-93 blend will further decrease emissions due to the higher alcohol content and lower hydrocarbon content.)

Pekin Energy Company supplies GROWMARK with anhydrous ethanol denatured with 2% kerosene. The ethanol is blended with 5% synthetic methanol to produce the E-93 ethanol fuel mixture. Since this blend is a qualified mixture, the blender can use the alcohol fuel credit and pass it through to the end user by selling the fuel at a reduced price.

Claiming the Alcohol Tax Credit:

The credit is claimed by using Form 6478 - "Credit for Alcohol Used as Fuel", filed with a federal income tax return. Limitations of the credit are:

- the credit is "non-refundable"; it can only be used to offset income tax liability.
- The credit cannot exceed:
  *100% of the tax liability up to $25,000 plus 75% of the amount over $25,000,
  or
  *the excess of net income tax over the computed minimum tax.

Unused credit can be carried back three years and then carried forward. Also, since the credit is intended to reduce the cost of the fuel sold, the credit must be included in taxable net income.

Tax Credit Computations:

The following is a cost comparison of straight gasoline, diesel fuel, E-85 ethanol fuel, and E-93 ethanol fuel:

	Gasoline		Diesel		E-85		E-93	
	Gal.	$	Gal.	$	Gal.	$	Gal.	$
Fuel Cost:								
Gasoline	10,000	4,800			1,500	720		
per gal.		48¢				48¢		
Diesel Fuel			10,000	5,600				
per gal.				56¢				
Methanol							500	590
per gal.								$1.18
Ethanol					8,500	9,180	9,500	10,260
per gal.						$1.08		$1.08
Total Cost	10,000	4,800	10,000	5,600	10,000	9,900	10,000	10,850
per gal.		48¢		56¢		99¢		$1.09
Alcohol Fuels Credit:								
Alcohol Used					8,500	(4,590)	9,500	(5,130)
credit per gal.						54¢		54¢
Cost Before Federal and State Tax, Distribution and Delivery Costs		4,800		5,600		5,310		5,720
per gal.		48¢		56¢		53¢		57¢

The computed cost assumes the fuel is used for a federally nontaxable purpose, such as by a state or local government. If sold for a federally taxable purpose, federal excise taxes would apply, and the alcohol credit is reduced by the benefit of any partial excise tax exemption.

Paperwork Reduction Act Notice

We ask for the information on this form to carry out the Internal Revenue laws of the United States. You are required to give us the information. We need it to ensure that you are complying with these laws and to allow us to figure and collect the right amount of tax.

The time needed to complete and file this form will vary depending on individual circumstances. The estimated average time is:

Recordkeeping	10 hr., 46 min.
Learning about the law or the form	34 min.
Preparing the form	1 hr., 42 min.
Copying, assembling, and sending the form to the IRS	16 min.

If you have comments concerning the accuracy of these time estimates or suggestions for making this form more simple, we would be happy to hear from you. You can write to both the IRS and the Office of Management and Budget at the addresses listed in the instructions for the tax return with which this form is filed.

General Instructions

Purpose of Form

Use Form 6478 to figure your credit for alcohol used as fuel. The credit consists of the following:

1. Alcohol mixture credit,
2. Alcohol credit, and
3. Small ethanol producer credit.

You may claim or elect not to claim the alcohol fuel credit at any time within the 3 years from the due date of your return (determined without regard to extensions) on either an original or an amended return.

Who Must File Form 3800

The general business credit consists of the investment credit (Form 3468), jobs credit (Form 5884), credit for alcohol used as fuel (Form 6478), research credit (Form 6765), low-income housing credit (Form 8586), enhanced oil recovery credit (Form 8830), disabled access credit (Form 8826), and renewable electricity production credit (Form 8835).

The Revenue Reconciliation Act of 1993 added the following four new credits: empowerment zone employment credit (Form 8844), Indian employment credit (Form 8845), credit for employer social security and Medicare taxes paid on certain employee tips (Form 8846), and credit for contributions to certain community development corporations (Form 8847). Generally, the new credits are allowed for expenditures incurred after December 31, 1993. See the above forms and **Form 3800,** General Business Credit, for other details.

If you have more than one of the credits for 1993, a carryback or carryforward of any of these credits, or a credit for alcohol used as fuel from a passive activity, you must also file Form 3800, which is used instead of lines 12 through 19 to figure the tax liability limitation.

Definitions and Special Rules

Alcohol.—Alcohol, for credit purposes, includes ethanol and methanol but does not include:

1. Alcohol produced from petroleum, natural gas, or coal (including peat), or
2. Alcohol of less than 150 proof. In figuring the proof of any alcohol, disregard any denaturants (additives that make the alcohol unfit for human consumption). The volume of alcohol includes any denaturant up to 5% of the volume of the alcohol and denaturant combined.

However, methanol produced from methane gas formed in waste disposal sites is not alcohol produced from natural gas, and is included for credit purposes.

Alcohol mixture.—The alcohol must be used to make a qualified mixture. A qualified mixture combines alcohol with gasoline, diesel, or special motor fuel. The producer of the mixture either:

1. Uses it as fuel, or
2. Sells it as fuel to another person.

The credit is available only to the producer who blends the mixture. The producer must use or sell the mixture in a trade or business and the credit is available only for the year the mixture is sold or used. The credit is not allowed for casual off-farm production of a qualified mixture.

Straight alcohol.—The alcohol must not be a mixture with gasoline, diesel, or special motor fuel (other than as a denaturant). The credit is for alcohol that during the tax year is:

1. Used by the taxpayer as a fuel in a trade or business, or
2. Is sold by the taxpayer at retail to another person and put in the fuel tan of that person's vehicle.

However, no credit is allowed for alcohol used by the taxpayer as a fuel in a trade or business if that alcohol was sold in a retail sale described in 2 above.

Qualified ethanol fuel production.—This is ethanol produced by an eligible small ethanol producer (defined below) and during the tax year:

1. Is sold by the producer to another person—

a. For use by the buyer in the buyer trade or business to produce a qualified mixture (other than casual off-farm production),

b. For use by the buyer as a fuel in trade or business, or

c. Who sells the ethanol at retail to another person and puts the ethanol i the retail buyer's fuel tank; or

2. Is used or sold by the producer for any purpose described in 1 above.

Eligible small ethanol producer.—Th is a person who, at all times during the tax year, has a productive capacity for alcohol of 30 million gallons or less. T includes alcohol made from petroleu natural gas, coal, peat, and alcohol of less than 150 proof.

Diesel fuel.—This is any liquid other than gasoline that can be used as a f in a diesel-powered highway vehicle.

Special motor fuel.—This is any liqui other than gasoline that is suitable fo use or is used in a motor vehicle or motor boat.

Noncommercial aviation.—This is th use of an aircraft other than in a business of transporting persons or property for pay.

Recapture of credit if not used as fuel.—You must pay the tax on each gallon of the alcohol or the alcohol in the mixture at the applicable rate that you used to figure the credit if you claim alcohol fuel credit and later you:

1. Separate the alcohol from the mixture,
2. Use the mixture other than as a
3. Mix straight alcohol on which th credit was allowed for the retail sale,
4. Use the straight alcohol other th as a fuel, or
5. Do not use the fuel for the purposes described under **Qualified ethanol fuel production.**

Report the tax on **Form 720,** Quar Federal Excise Tax Return.

Specific Instructions

Use lines 1 through 9 to figure any alcohol fuel credit from your own trade or business.

Note: *We have shown in column (b) the rate for ethanol only. If you have a credit for alcohol other than from ethanol, enter in column (b) the applicable rate shown in the instructions for lines 2a, 2b, and 7a through 7d.*

Skip lines 1 through 9 if you are claiming only a credit that was allocated to you from a flow-through entity (i.e., S corporation, partnership, estate, or trust).

S corporations, partnerships, estates, and trusts.—Figure the total credit on lines 1 through 11. Then allocate the line 11 credit to each shareholder, partner, and beneficiary in the same way that income and loss are divided.

If the line 11 credit includes any small ethanol producer credit (line 1), you must separately state to each shareholder, partner, beneficiary, etc., the number of gallons on which the credit was figured, and the productive capacity for alcohol that you, the pass-through entity, have. State the productive capacity in terms of gallons.

Line 1.—Enter the number of gallons of ethanol that meet the conditions listed on page 3 under **Qualified ethanol fuel production.** Do not enter more than 15 million gallons. Multiply by the rate of 10 cents per gallon.

Line 2.—Enter on the appropriate line the number of gallons sold or used.

Line 2a.—Enter the number of gallons of 190 proof or greater alcohol and multiply by the rate.

For alcohol other than from ethanol, the rate is 60 cents per gallon.

Line 2b.—Enter the number of gallons of alcohol that is less than 190 proof but at least 150 proof and multiply by the rate.

For alcohol other than from ethanol, the rate is 45 cents per gallon.

Line 4.—Enter the number of gallons of other fuels that you blended with the alcohol shown on lines 2a and 2b. Other fuels include gasoline, diesel, and special motor fuels.

Line 5b.—Enter the number of gallons included on line 5a that contain less than 5.7% of 190-proof alcohol or are exempt from excise taxes. The fuel can be exempt because of specific exemption, credit, or refund provisions other than the alcohol fuel credit. Examples of fuels exempt from excise tax include fuel that is:

- Used on a farm for farming purposes.
- Supplied to military ships or aircraft or certain commercial ships or aircraft.
- Used in off-highway business use.
- Used as fuel by a state, any political subdivision of a state, or the District of Columbia.
- Used as fuel by a nonprofit educational organization.
- Used in an intercity, local, or school bus.
- Used for certain helicopter uses.

Line 7.—If you sold or used alcohol or an alcohol mixture as fuel, you may have been entitled to an exemption from excise tax or a reduced rate of excise tax. The alcohol fuel credit must be reduced to take into account any benefit provided by that exemption or reduced rate.

Line 7a.—Enter on line 7a the number of gallons of aviation fuel sold for use in or used in noncommercial aviation that is alcohol or alcohol blended with aviation fuels other than gasoline.

The benefit for alcohol other than from ethanol or alcohol other than from ethanol blended with aviation fuels (other than gasoline) is 13.61 cents per gallon for fuel sold or used before January 1, 1994. The benefit for this fuel sold or used after December 31, 1993, is 13.13 cents per gallon.

Line 7b.—Enter on line 7b the number of gallons of aviation fuel sold for use in or used in noncommercial aviation that is alcohol blended with gasoline.

The benefit for alcohol other than from ethanol blended with gasoline is 5.11 cents per gallon for fuel sold or used before October 1, 1993. The benefit for this fuel sold or used after September 30, 1993, is 4.63 cents per gallon.

Lines 7c and 7d.—This includes all other uses that received an excise tax benefit because the fuels contained alcohol (e.g., gasoline bought at a reduced rate to produce gasohol). Include only fuel mixtures that received an excise tax benefit because the fuel contained alcohol.

Line 7c.—Enter the number of gallons of fuel that is a mixture containing less than 85% alcohol.

The rates are based on the percentage of alcohol in the mixture.

Percentage of alcohol in mixture	Rate: Ethanol	Rate: Other than ethanol
At least 10%	.054	.060
At least 7.7% but less than 10%	.0416	.0462
At least 5.7% but less than 7.7%	.0308	.0342

Line 7d.—Enter the number of gallons of fuel that contain 85% or more alcohol.

For alcohol other than from ethanol, the benefit is 6.05 cents per gallon.

Line 9.—Include this amount in income, under "Other income" on the appropriate line of your income tax return, even if you cannot use all the credit because of the tax liability limitation.

Line 10.—Enter the amount of credit that was allocated to you as a shareholder, partner, or beneficiary.

If your credit from a flow-through entity includes the small ethanol producer credit, the flow-through entity must tell you the amount of the small producer credit included in the flow-through credit, the number of gallons for which the entity claimed the small ethanol producer credit, and the productive capacity for alcohol. You as a shareholder, partner, beneficiary, etc., are subject to the 15-million-gallon limitation for line 1 and the 30-million-gallon productive capacity limitation for an eligible small ethanol producer. If you receive a small ethanol producer credit from more than one entity, your credit may be limited.

Line 11.—If you have more than one of the credits listed under **Who Must File** Form 3800 or a credit for alcohol used as fuel from a passive activity, stop here and go to Form 3800.

If you have only a 1993 credit for alcohol used as fuel, and the credit is not from a passive activity, complete this form. You do not have to file Form 3800 for this year.

For an estate or trust, the credit on line 11 is allocated among the beneficiaries in the same manner as the income was allocated. In the margin to the right of line 11, the fiduciary of the estate or trust identifies its share and the beneficiaries' shares of the total credit. Complete lines 12 through 19, as applicable, to figure the credit to take on Form 1041. Attach a schedule to Form 6478 showing how the total credit was divided.

Line 15.—Enter the tentative minimum tax (TMT) that was figured on the appropriate alternative minimum tax (AMT) form or schedule. Although you may not owe AMT, you must still compute the TMT to figure your credit.

Line 17.—See section 38(c)(3) for special rules for married couples filing separate returns, for controlled corporate groups, and for estates and trusts.

Line 19.—If you cannot use part of the credit because of the tax liability limitations, carry it back 3 years, then forward for 15 years. See the separate Instructions for Form 3800 for details.

Form **6478**

Department of the Treasury
Internal Revenue Service

Credit for Alcohol Used as Fuel

▶ Attach to your return.

▶ For Paperwork Reduction Act Notice, see instructions.

OMB No. 1545-0231

1993

Attachment Sequence No. **83**

Name(s) as shown on return | **Identifying number**

	Type of Alcohol Fuel		(a) Number of Gallons Sold or Used	(b) Rate *	(c) Column (a) x Column (b)
1	Qualified ethanol fuel production (in gallons)	1		.10	
2	**Straight alcohol and alcohol mixtures:**				
a	190 proof or greater (in gallons)	2a		.54	
b	Less than 190 proof but at least 150 proof (in gallons)	2b		.40	
3	Add lines 1, 2a, and 2b in both columns	3			
4	Other fuels blended with the alcohol on lines 2a and 2b	4			
5a	Total gallons of fuel. Add lines 3 and 4 (column (a)).	5a			
b	Total gallons containing less than 5.7% of 190-proof alcohol or that are exempt from excise taxes (see instructions)	5b			
6	Subtract line 5b from line 5a	6			
7	Break down line 6 into the number of gallons of:				
	For use in noncommercial aviation:				
a	Alcohol or alcohol blended with aviation fuels	7a		.1293 (.1246**)	
b	Alcohol blended with gasoline for aviation fuel	7b		.0444 (.0396***)	
	All other uses:				
c	Less than 85% alcohol blended with fuel (see instructions)	7c		(See instructions)	
d	85% or more alcohol (see instructions).	7d		.0545	

8	Add lines 7a through 7d, column (c)	8	
9	Current year credit less excise tax benefit. Subtract line 8 from line 3. Include this amount in your income for 1993.	9	
10	Flow-through alcohol fuel credit(s) from a partnership, S corporation, estate, or trust (see instructions)	10	
11	**Total current year credit for alcohol used as fuel.** Add lines 9 and 10	11	

*Only the rate for ethanol is shown. See instructions for lines 2 and 7 for rates for alcohol other than ethanol.

**Rate effective after December 31, 1993. ***Rate effective after September 30, 1993.

See ***Who Must File Form 3800*** *to see if you complete the lines below or file Form 3800.*

12a	Individuals. Enter amount from Form 1040, line 40				
b	Corporations. Enter amount from Form 1120, Schedule J, line 3 (or Form 1120-A, Part I, line 1)			12	
c	Other filers. Enter regular tax before credits from your return				
13	Credits that reduce regular tax before the credit for alcohol used as fuel:				
a	Credit for child and dependent care expenses (Form 2441, line 10)	13a			
b	Credit for the elderly or the disabled (Schedule R (Form 1040), line 21)	13b			
c	Mortgage interest credit (Form 8396, line 11)	13c			
d	Foreign tax credit (Form 1116, line 32, or Form 1118, Sch. B, line 12)	13d			
e	Possessions tax credit (Form 5735, line 14)	13e			
f	Orphan drug credit (Form 6765, line 10)	13f			
g	Credit for fuel from a nonconventional source	13g			
h	Qualified electric vehicle credit (Form 8834, line 17)	13h			
i	Add lines 13a through 13h			13i	
14	Net regular tax. Subtract line 13i from line 12			14	
15	Tentative minimum tax (see instructions):				
a	Individuals. Enter amount from Form 6251, line 26				
b	Corporations. Enter amount from Form 4626, line 14			15	
c	Estates and trusts. Enter amount from Form 1041, Schedule H, line 37				
16	Net income tax:				
a	Individuals. Add line 14 above and line 28 of Form 6251				
b	Corporations. Add line 14 above and line 16 of Form 4626			16	
c	Estates and trusts. Add line 14 above and line 39 of Form 1041, Schedule H				
17	If line 14 is more than $25,000, enter 25% (.25) of excess (see instructions)			17	
18	Subtract line 15 or line 17, whichever is greater, from line 16. If less than zero, enter -0-			18	
19	**Credit for alcohol used as fuel allowed for the current year.** Enter the **smaller** of line 11 or line 18. This is your **General Business Credit** for 1993. Enter here and on Form 1040, line 44; Form 1120, Schedule J, line 4e; Form 1120-A, Part I, line 2a; or the appropriate line of other income tax returns			19	

Cat. No. 13605J

Appendix 2

The Ethanol Heavy Duty Truck Fleet Demonstration Program

Note: This paper was originally published in *Proceedings, Volume #1, The Tenth International Symposium on Alcohol Fuels*, Colorado Springs, Colorado, 1993.

THE ETHANOL HEAVY DUTY TRUCK FLEET DEMONSTRATION PROGRAM

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ABSTRACT

The purpose of this project is to determine the performance, reliability, cost of operation and emissions from over-the-road trucks operating on high percentages of ethanol fuel and represents the first information collected on these types of vehicles.

The first fleet of four ethanol trucks, owned and operated by ADM, are 1992 White-GMC WIM64T models powered by Detroit Diesel Corporation (DDC) 300 horsepower, dedicated ethanol 6V-92TA engines with 9-speed manual transmissions. Initially, the trucks are being operated on short routings, allowing them to return to the terminal each night. Eventually, interstate routings will be included as part of the program.

The emissions testing data for this program has been performed by the U.S. DOE \ University of West Virginia Transportable Emissions Testing Center.

The data from this project is being sent to NREL for use in the National Alternative Fuels Database.

THE ETHANOL FUEL HEAVY-DUTY TRUCK FLEET DEMONSTRATION PROGRAM

Introduction

The State of Illinois, through the Illinois Department of Energy and Natural Resources (ENR), is testing and evaluating the use of high percentages of anhydrous ethanol as an alternative transportation fuel. ENR has been working for several years with original equipment manufacturers (OEM) on the production of vehicles optimized for ethanol fuel to be used for test and demonstration purposes. One such demonstration program is the Ethanol Fuel Heavy-Duty Fleet Demonstration Program where ethanol substitutes for diesel fuel in heavy-duty, over-the-road trucks.

The Detroit Diesel Corporation (DDC) Model 6V-92TA is the first commercially available heavy-duty truck, urban transit, touring, and school bus engine optimized for alcohol fuels. The first DDC 6V-92TA pre-production methanol engine was put into service in 1983 in an urban transit bus fleet in California. Currently, fifty-seven (57) pre-production and several hundred 6V-92TA methanol engines have been produced. This engine was USEPA and CARB emissions certified in mid-1991.

In 1991, the first two DDC 6V-92TA pre-production ethanol engines were installed in urban transit buses in Canada. Each bus logged over 30,000 miles in the first year of operation with very little down time. By late 1992, the engine was USEPA and CARB emissions certified. The first and largest American fleet of fourteen (14) 6V-92TA 253 horsepower, ethanol fuel urban transit buses began operations in Peoria, Illinois in 1992. Also in 1992, the first and largest American ethanol fuel, heavy-duty truck fleet demonstration program was put into service in Illinois. This fleet of four (4) White-GMC over-the-road trucks is owned and operated by Archer Daniels Midland (ADM) of Decatur, Illinois and is based on DDC 6V-92TA dedicated ethanol engines. The ethanol truck engines differ somewhat from the engines used in the Peoria buses in that they have been factory-programmed for 300 horsepower, rather than 253 horsepower.

Participants in the program include Archer Daniels Midland, Detroit Diesel Corporation, USDOE, the National Renewable Energy Laboratory (NREL) and the Illinois Department of Energy and Natural Resources (ENR). The USDOE / University of West Virginia Transportable Emissions Testing Laboratory is also a major contributor to the project by performing the emission tests on the ethanol and diesel control trucks.

The Project

In 1991, USDOE requested the State of Illinois Department of Energy and Natural Resources (ENR) to develop a test and demonstration program for over-the-road trucks operating on ethanol fuel. This heavy-duty, over-the-road truck program was authorized under the Alternative Motor Fuels Act (AMFA) of 1988. Based on this request, ENR, in partnership with ADM, DDC, and NREL, initiated this comprehensive test and demonstration effort with a fleet of the first ethanol powered, over-the-road trucks in the nation.

Goals and Objectives

Unlike methanol and natural gas, the use of high percentage ethanol fuel blends for transportation purposes has been limited to only a few localized demonstration projects. Trucks, buses, and passenger cars optimized for ethanol fuels have simply not been available from the original equipment manufacturers due, primarily, to a lack of demand for such vehicles. A lack of established refueling facilities is a second factor. The performance and reliability of ethanol vehicles under actual field conditions has not been adequately documented. Further, until recently, very little emissions data on high percentage ethanol fuel vehicles has been available.

Ethanol is currently one of the only cost-effective, renewable transportation fuels on the market. Ethanol is made primarily from corn, a crop grown in great abundance every year throughout the Midwest. Illinois is the leading producer of ethanol in the country. Annually, over 500 million gallons of gasoline-quality, anhydrous ethanol is produced in Illinois using almost 200 million bushels of Illinois corn. Illinois is also the leading user of 10% blended ethanol gasoline in the nation. Over 150 million gallons of ethanol is used to substitute for gasoline every year and a full 30% of all the gasoline sold in Illinois contains ethanol.

Because it has a higher BTU content per unit volume than methanol, anhydrous ethanol (76,000 BTU's per gallon) can be compared more favorably to diesel fuel than anhydrous methanol (57,000 BTU's per gallon). Most of ethanol's other chemical properties are also closer to diesel fuel than methanol fuel. Ethanol is also considerably less toxic and less corrosive than methanol. Finally, ethanol, being a liquid fuel, does not have the pressure or refueling problems commonly associated with CNG or propane gas.

The Ethanol Fuel Heavy-Duty Truck Fleet Demonstration Program is assessing the performance, reliability, durability and emissions from heavy-duty, over-the-road trucks operating on ethanol as the primary fuel and the role of ethanol fuel in meeting the regulations imposed by the Clean Air Act (CAA) of 1990. These trucks are being used under normal field conditions where the maximum amount of data can be generated. The ethanol trucks have also been emission tested by the USDOE / University of West Virginia Transportable Emissions Testing Laboratory.

The Fleet Operator

The first fleet of heavy-duty, over-the-road ethanol trucks is owned and operated by Archer Daniels Midland (ADM) of Decatur, Illinois. ADM is the largest producer of gasoline-quality (less than 1% water content by volume), anhydrous ethanol in the nation and operates a fleet of over 800 vehicles. The ADM Trucking, Incorporated subsidiary operates the fleet trucks for the company and will be required to conform to the regulations established for truck fleet operators under the Clean Air Act. It would only make sense, then, that ADM be a logical choice as the first fleet operator for this program.

The ethanol truck fleet is operated out of the ADM Trucking facility in Decatur, Illinois. ADM Trucking services its vehicles both in-house and through local dealerships. The ethanol trucks are used to deliver shipments of liquefied carbon dioxide (CO2) to destinations in Illinois, Indiana and Wisconsin where the trucks can leave the facility each morning and return to the Decatur facility each evening.

The Fuel

The DDC 6V-92TA dedicated ethanol engines used in this program operate on "E-95" ethanol fuel. The "E-95" fuel is essentially a mixture of 95% 200-proof, anhydrous ethanol and 5% light hydrocarbon denaturant (Figure 1). A very small amount (less than 0.1%) of a special lubricating agent, Lubrizol, is added to the fuel mixture to provide upper cylinder lubrication. ADM Corn Processing produces the ethanol fuel on-site at the Decatur facility. The fuel is delivered to the ADM Trucking facility where it is stored and dispensed from a 5,000 gallon aboveground storage tank. The 5% light hydrocarbon denaturant, called "natural gasoline", is a mixture of C4 and C5 (butane and pentane) hydrocarbons and is purchased from the various oil refineries in the Midwest. The energy content of the E-95 ethanol fuel (including the 5% natural gasoline energy content) is approximately 78,000 BTU's per gallon, compared to the ASHRAE value of about 138,000 BTU's per gallon for #2 diesel fuel. Based on this, the ethanol fuel used in this test and demonstration project contains about 57% of the energy per gallon as the #2 diesel fuel used in conventional diesel trucks.

The Vehicles

The ADM ethanol fleet is composed of four ethanol powered trucks and one identical truck equipped with a conventional diesel engine that serves as a control unit for the program. ADM selected 1992 White-GMC WIM64T trucks because the Detroit Diesel 6V-92TA engines could be installed easily without chassis or frame modifications. The trucks can be easily identified by the words "Ethanol 95" and a ring of corn kernels on each fuel tank.

The four ethanol trucks are powered by DDC 6V-92TA ethanol engines. These are dedicated engines that have been optimized for the E-95 ethanol fuel previously mentioned. The engines are six cylinder, 552 cubic inch, vee-configuration engines that have been factory programmed for 300 brake horsepower. The development of the ethanol 6V-92TA was based on DDC's previous experiences with the methanol version of this engine. Numerous engine modifications were necessary to optimize the engines for ethanol fuel. Because of the lower energy content of ethanol (compared to diesel fuel), ethanol-tolerant high capacity fuel injectors and fuel pumps were installed. Special glow plugs were installed in redesigned piston heads to enhance compression ignition, especially in cold weather. The glow plugs operate for one minute before the engine can be started and remain on until normal engine operating temperatures are attained. A Detroit Diesel Electronic Control (DDEC), which is an electronic unit fuel injector and engine management control system, has been installed on each engine. A catalytic converter has been added to further reduce emissions. A five minute "kill" switch has been installed that shuts the engines off automatically after five minutes of low-idling time. Additional modifications include ethanol tolerant fuel lines and an increased engine compression ratio of 23.0 : 1.0. Except for the increased horsepower and torque, the 6V-92TA ethanol engines are identical to the engines used in the Peoria Ethanol Bus Project. The control truck uses a conventional DDC 6V-92 diesel engine (without a catalytic converter) with electronics and specifications identical to the ethanol engines. The transmissions used in all of the trucks is the Fuller Model RTX-12609B, which has nine (9) forward speeds plus a reverse gear. The rear axle is a Rockwell RT40-140, with a final ratio of 4.56 : 1.00. The wheelbase for the trucks is 206 inches and they are equipped with cruise control and block heaters.

The trucks were built at the White-GMC factory in Kentucky. Conventional DDC 6V-92TA engines were installed at the factory. One of the trucks was shipped to ADM in Decatur directly as the control truck for the program. The other four trucks were shipped to DDC in Detroit, Michigan where the engines were modified for ethanol fuel usage. After the ethanol engine modifications were completed (approximately six weeks), the trucks were shipped to ADM.

The curb weight of each tractor truck is about 17,400 pounds and the gross vehicle weight of the truck with an empty CO_2 tanker trailer is about 33,000 pounds. The maximum gross vehicle weight is approximately 78,000 pounds.

Each of the four ethanol trucks and the control diesel truck have two 120 gallon, side-mounted fuel tanks. The range on the ethanol truck is approximately 800 miles while the range on the diesel control truck is about 1,100 miles between refuelings. Because of the this differential in mileage and the limited availability of E-95 fuel, the ethanol trucks are currently being operated on routes that will allow them to leave the ADM facility every morning and return to Decatur every evening. Eventually, it is being planned that E-95 refueling facilities will be located at ADM truck terminals in Iowa and Missouri to increase the range of the vehicles and demonstrate the truck fleet in other parts of the Midwest.

Routes and Duty Cycles

An important part of this program is to evaluate the performance of a heavy-duty, ethanol powered truck fleet under actual field conditions. Except when one of the vehicles is pulled from service for a promotional event or mechanical servicing, the trucks are operated every working day delivering products from the ADM plant in Decatur, Illinois. One driver has been assigned to each of the four ethanol trucks and the control diesel truck so that the results obtained from each vehicle will remain consistent throughout the tests. The driver of each vehicle will be accustomed to the operation of that specific vehicle and will be able to determine if something is wrong simply by the way it performs on the road.

The control diesel and the four ethanol trucks are being used to transport liquefied CO2 from Decatur to cities like Chicago, Indianapolis and St. Louis. Each truck runs to different delivery points to vary the operation times and conditions. Eventually, it is planned that additional E-95 refueling facilities will be established in Iowa and Missouri to increase the range of the vehicles and expand the program to other areas of the Midwest. At this time, a typical duty cycle would be a few minutes of low to moderate speed (ADM is located on the outskirts of Decatur), several hours of highway driving, followed by one to two hours of low speed, stop-and-go driving in the major cities to make the delivery, several more hours of highway speed driving, and then a few more minutes of low to moderate speed driving in Decatur. Idling time is generally kept to a minimum because of the 5 minute kill switches installed in the trucks. If the truck is left unattended on low idle for five minutes, the engine will automatically be turned off. Overall, the ethanol trucks are averaging over 6,000 miles per vehicle per month. Because of the considerable amount of highway driving being done, the average speed of the vehicles often exceeds 45 miles per hour. The average load of a full CO2 trailer is about 37,000 pounds for a gross vehicle weight of approximately 54,400 pounds.

Results from Operations

A considerable amount of data is being generated and collected as a result of this project. Several tests and demonstrations on the operation of heavy-duty truck fleets using methanol and compressed natural gas fuels are currently underway in this country. By contrast, this project is the first application of heavy-duty, dedicated ethanol engines in an over-the-road truck fleet.

Vehicle Performance

Fuel economy is one of the most important parameters when considering overall vehicle performance. One gallon of anhydrous, E-95 ethanol fuel (denatured with 5% natural gasoline) contains about 78,000 BTU's. According to ASHRAE, one gallon of #2 diesel fuel contains about 138,000 BTU's. Based on these numbers, the E-95 fuel has about 57% of the energy contained in #2 diesel fuel per unit volume. The anticipated fuel economy of an ethanol powered truck, then, should be 57% of an equivalent diesel truck, assuming the loads and duty cycles were the same. However, this is not the case with the ADM ethanol truck fleet. The diesel control truck has been averaging 5.30 miles per gallon in all around use. The four ethanol trucks have been averaging 4.00 miles per gallon, almost one full mile per gallon over the expected 3.02 miles per gallon. It is possible that a small amount of steam effect (from the less than 1% water allowable in anhydrous ethanol) may be partially responsible for this 30%+ increase in fuel economy. It seems more likely, though, that the engine simply runs more efficiently when optimized for the E-95 fuel.

Emissions testing is another integral part of this test and demonstration project. Detroit Diesel Corporation performed an engine calibration and transient emissions test in a factory testing cell. The transient emissions test data obtained from the test cell is displayed in Table 1. Briefly, the emissions from the pre-production 6V-92TA ethanol engine easily pass the 1994 CAA standards for this type of engine. Since the ethanol engines used in this program were built, the DDC 6V-92TA ethanol engine has been USEPA and CARB emission certified and is now considered a regular production Detroit Diesel engine.

The USDOE / University of West Virginia Transportable Emissions Testing Center first tested the control diesel truck and one of the ethanol trucks in July 1992. The ethanol trucks did not perform as well as predicted (please refer to Table 2). There are two explanations for the this. First, because the sixteen tandem wheel tires were badly worn on the two trucks as a result of the testing, it is likely that the truck was not properly aligned on the treadmill, or the load on the truck applied. Secondly, the emissions testing duty cycle used by West Virginia was primarily designed for buses with automatic transmissions. Basically, the duty cycle calls for steady acceleration to a given speed in a predetermined amount of time, level off at that speed, then decelerate and stop. It is relatively easy for a bus to meet this type of duty cycle since the automatic transmission does not require manual gear shifting during the testing process. Unfortunately, a truck with a 9-speed manual transmission requires several gear shifts to accelerate to a certain speed. This may lead to erroneous reading in the emission levels because of the gear shifts and the attempt to meet the acceleration time requirements. A new emissions testing duty cycle program is currently being developed by West Virginia to account for the shifting of transmission gears during acceleration.

ADM has been keeping computerized maintenance and cost of operation records on all five of the trucks. DDC has also provided considerable engineering and field support for this program. A DDC representative was scheduled to be on-site two days per week for the first two months, once every week for the next ten months and once every two weeks for the next year. Complete site visit reports have been prepared by DDC describing the nature of the visit and any work required on the vehicles.

In the past, fuel injectors on these engines represented a potential problem. The pre-production methanol 6V-92TA engines encountered serious plugging problems after only a few thousand miles and had to be replaced after only 3,000 miles. This problem seems to have been nearly eliminated in the ethanol truck fleet. Fuel injectors on the four 6V-92TA ethanol engines have lasted between 75,000 and 85,000 miles before replacement was necessary.

To this point, the reliability of the 6V-92TA ethanol engine is as good or slightly better than its diesel counterpart. Two of the four vehicles have already accumulated over 100,000 miles each with minimal downtime. The other two vehicles will pass the 100,000 mile marker by mid-summer of 1993. The drivers of the trucks have also been very pleased with their performance.

REFERENCES

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Detroit Diesel Corporation 1992. *Transient Engine Test Data (Ethanol Fuel)*. Detroit, Michigan: Detroit Diesel Corporation.

Marek, Norman J. 1993. "Benefits To Illinois In Developing and Utilizing Ethanol Fuels." Springfield, Illinois: Illinois Department of Energy and Natural Resources. (In publication).

West Virgina University 1992. *Transportable Heavy Duty Vehicle Emissions Testing Laboratory - Test Results Report. Morgantown, West Virginia: West Virginia University.*

TABLES AND FIGURES

Figure 1 - E-95 Ethanol Fuel Specifications

Chemical Composition:	C_2H_5OH - Ethyl Alcohol
Fuel Composition:	95% 200 Proof, Anhydrous Ethyl Alcohol (Ethanol)
	5% Natural Gasoline (C4 and C5 Hydrocarbons) or Unleaded Gasoline Denaturant
	Trace (less than 0.1%) Lubrizol Upper Cylinder.Lubricant
Energy Content:	Approximately 78,000 BTU's Per Gallon Volume. Based on 76,000 BTU's Per Gallon of Anhydrous Ethanol and 118,000 BTU's Per Gallon of Unleaded Gasoline.
Boiling Point:	78 to 79 Degrees C
DOT Designation:	Flammable Liquid.
Harmful Effects:	Local - Mild Irritation of Nose and Eyes Occurs at Very High Concentrations. The Liquid Can Defat the Skin.
	Systemic - Prolonged Inhalation of High Concentrations, Besides the Local Effect on the Eyes and Upper Respiratory System, May Produce Headache, Drowsiness, Tremors and Fatigue.
First Aid:	Irrigate With Water.

Table 1 - Detroit Diesel Corporation Model Year 1992 E-95 6V-92TA Emissions Certification Numbers

	ENGINE ID	TEST LOC.	PROJECT EXHAUST EMISSIONS SMOKE % ACCEL	LUG	PEAK	(GRAMS PER HORSEPOWER-HOUR) OMCHE	CO	NOx	PART.
TEST ENGINE (Includes Deterioration Factor)	6VF103279	SWRI	1.2	2.2	5.0	0.73	1.71	4.15	0.04
1994 EMISSIONS STANDARDS						1.30	15.50	5.00	0.10

Table 2 - University of West Virginia Emissions Testing Results Average Emissions (Grams/Mile)

UNIT	FUEL	CO	NOx	HC	PM	CO_2	MI/GAL	BTU/MILE
92006	Ethanol	17.76	21.066	7.78	0.25	3408.9	2.18	59.118
92010	#2 Diesel	9.35	24.142	3.59	2.07	3668.9	2.76	47.204

Appendix 3

West Virginia University
Transportable Heavy-Duty Vehicle
Emissions Testing Laboratory

Test Results Report
August 1993

WEST VIRGINIA UNIVERSITY

TRANSPORTABLE HEAVY DUTY VEHICLE EMISSIONS TESTING LABORATORY

Test Results Report

for

Archer Daniel Midland Co.

Department of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26506
Phone: (304) 293-3111
FAX: (304) 293-6689

August 20, 1993

TRANSPORTABLE HEAVY DUTY VEHICLE EMISSIONS TESTING LABORATORY

Conducted by:

Department of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26506-6101
Phone: (304) 293-3111
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Faculty Investigators:

Donald W. Lyons
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Lab Staff:

Byron Rapp
Curtis Leasor
Vincent Judy
Gary England
George Utt
James Kopasko
Sunil Katragadda

Sponsored by:

U.S. Department of Energy (DOE)
Office of Transportation Technologies
Office of Alternative Fuels - Fuel Utilization Data and Analysis
Program Manager: John Garbak

The West Virginia University (WVU) Transportable Heavy-Duty Vehicle Emissions Testing Laboratory traveled from Morgantown, West Virginia to Peoria, Illinois, and tested 3 vehicles belonging to Archer Daniel Midland Co. on June 13 thru June 25, 1993.

The test and calibration procedures of Code 40 of the Federal register (CFR-40), relevant to chassis testing, were followed whenever applicable.

The central business district (CBD) testing cycle, which simulates the driving pattern in an urban area, was used in the tests. The sketch of this cycle is shown in Figure 1. The cycle has 14 identical ramps, each of which takes 40 seconds. Each ramp allows 10 seconds for acceleration, 18.5 seconds for a constant speed of 20 mph, 4.5 seconds for deceleration, and 7 seconds for idling. The driving distance of the cycle is 2 miles.

The exhaust gas emissions were measured using the following analyzers: non-dispersive infrared analyzer (NDIR) for Carbon Monoxide (CO) and carbon dioxide (CO_2); chemiluminescent detector (CLD) for Oxides of Nitrogen (NO_x); and heated flame ionization detector (FID) for total hydrocarbon emissions. Particulate matter (PM) was measured by using a double dilution exhaust gas sample drawn over 70-mm fluorocarbon coated glass fiber filters for gravimetric analysis.

For alcohol fueled vehicles, the unburned methanol or ethanol in the exhaust was sampled by continuously bubbling a sample of diluted exhaust through impingers filled with deionized water. Silica cartridges coated with a 2,4 dinitrophenyhydrazine (DNPH) were used to measure the carbonyl compounds in the exhaust. The organic material hydrocarbon equivalent mass (OMHCE) emissions were also calculated.

The following test procedures were followed:

1. Position and mount the vehicle onto the test bed.
2. Warm up until the differentials of the dynamometer reach 100 °F.
3. Stop the engine and allow a 20 minute cool down (soak) period.
4. Start the engine and begin test.
5. At the end of test, cool down for 20 minutes and prepare for another test.

Typically three to six repetitive tests were conducted and the test results are reported for the individual tests and for the average of the tests. Both continuous sampling and bag sampling were employed. All data are reported in grams per mile (gm/mi).

NOTE: This test data should not be compared with the 1990 Clean Air Act emissions standard that used FTP for urban busses and trucks, which is given in grams per horsepower (gm/bhp), which is different from the Chassis Dynamometer test data reported here.

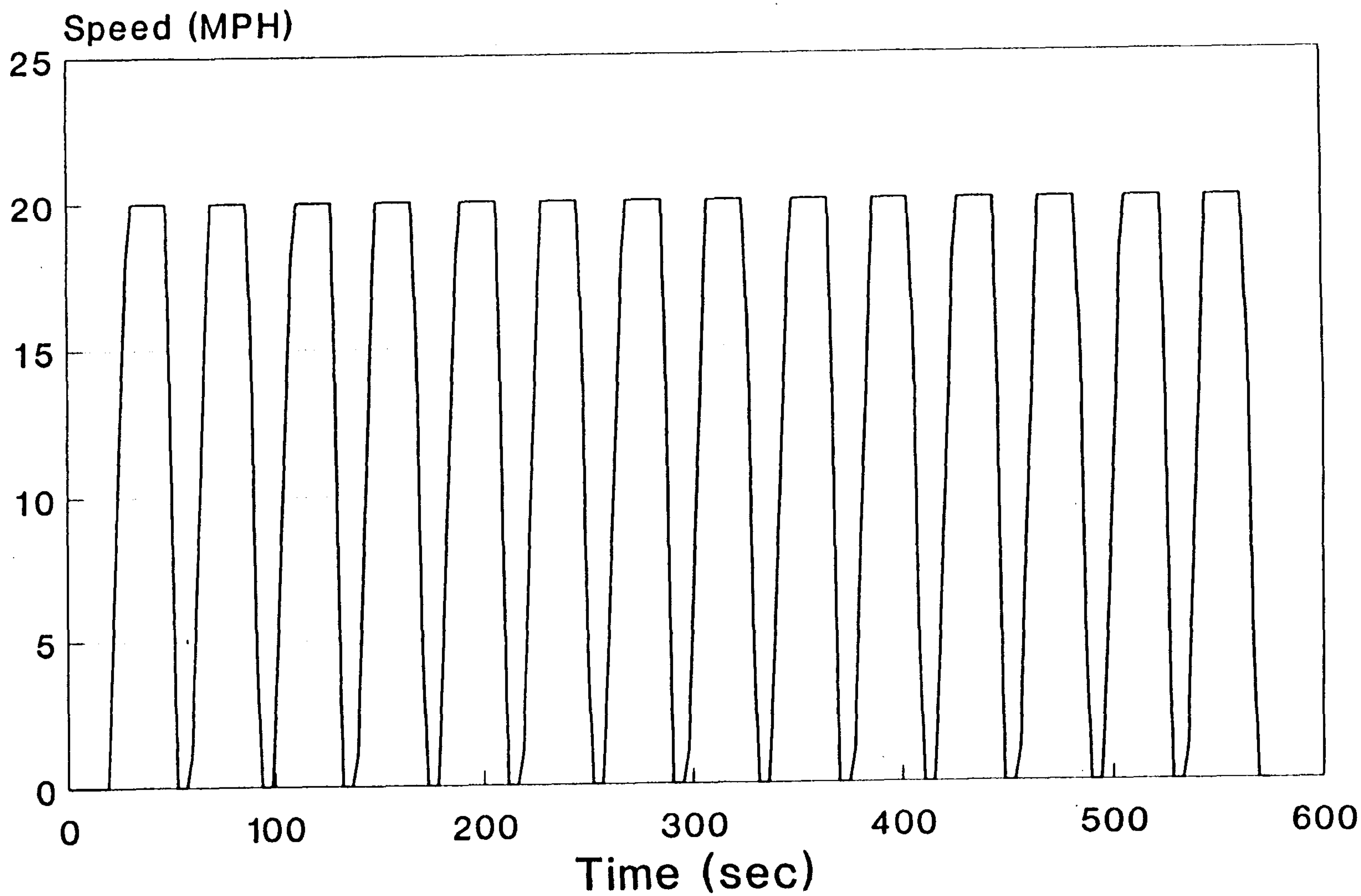

Figure 1 CBD Driving Cycle

TRANSPORTABLE HEAVY DUTY VEHICLE EMISSIONS TESTING LABORATORY

Conducted by: Department of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26506
Phone: 304-293-4111

Test Site: Greater Peoria Mass Transit District
2105 NE Jefferson Avenue
Peoria, IL 61603
Phone: (309) 676-8015

Sponsored by: U.S. Department of Energy (DOE)

TEST SCHEDULE for Archer Daniel Midland Co.

Test Sequence Number	WVU Test Reference Number	Test Date	Vehicle Manufacture	Engine Type	Vehicle type & No.	Fuel Type	# of Runs
159	ADM2-92006-ETHNL	6-21-93 Monday	WHITE GMC	DDC 6V-92	Truck 92006	95% ETHANOL	6
160	ADM2-92004-ETHNL	6-22-93 Tuesday	WHITE GMC	DDC 6V-92	Truck 92004	95% ETHANOL	6
161	ADM2-92010-2D	6/22/93 Tuesday	WHITE GMC	DDC 6V-92	Truck 92010	#2 DIESEL	5

Symbols or Abbreviations in the report

Test Sequence Number	= Unique number assigned to each test with the date order
WVU Test Reference Number	= Unique number assigned to each test, including the agency, vehicle number, fuel and aftertreatment if any
Test Cycle	= Driving pattern of the test
Gross Vehicle Weight	= Maximum legal weight at which the vehicle can be operated (GVW)
Test Weight	= GVW - 0.5 $\times$ (seating+standing) $\times$ 150 + 150 (lbs) or Curb weight + 0.5 $\times$ (seating+standing) $\times$ 150 + 150 (lbs)
AfterTreatment	= Exhaust control
HC	= Total hydrocarbons for non-alcohol fuel in exhaust
CO	= Carbon monoxide in exhaust
NOx	= Oxides of nitrogen in exhaust
PM	= Particulate matter in exhaust
CO_2	= Carbon dioxide in exhaust
OMHCE	= Organic material hydrocarbon equivalent in exhaust
CH_3OH	= Methanol in exhaust
C_2H_5OH	= Ethanol in exhaust
HCOH	= Formaldehyde in exhaust
CH_3CHO	= Acetaldehyde in exhaust
FID-HC	= Total hydrocarbons measured by FID
RHC	= Residual Hydrocarbon (= FIDHC - r $\times$ CH_3OH), r is FID response to CH_3OH
Mile/Gal	= Fuel economy calculated by carbon balance method. For CNG, it is assumed that 137 ft^3 at STP is equal to 1 gallon of #1 diesel.
Btu/mile	= Energy supply per mile

Test Sequence Number: 159
WVU Test Reference Number: ADM-92006-ETHNL

Agency:	ADM TRUCKING
Contact Person:	SAM RICHARDSON
Telephone Number:	(217)-424-2651
Vehicle Type (Bus/Truck):	TRACTOR
Vehicle Serial Number:	4V1YDBUE6NN649452
Vehicle Manufacturer:	WHITE GMC
Vehicle's Model Year:	1992
Gross Vehicle Weight Rating (GVWR-lbs)	80000
Vehicle Curb Weight (lbs)	23688
Vehicle Seating Capacity	2
Vehicle Standing Capacity	0
Vehicle Testing Weight (lbs)	40000
Odometer Reading (miles)	26336-HUB-102098-OD
Transmission Type: Auto/Manual	MANUAL
Transmiss. Config.:	9-SPEED
Outside Tire Dia.(in.)	43.05
Frontal Area of Vehicle (sq. ft.)	68.0
Tailpipe O.D.(in.)	5"
Fuel Tank(s) Capac.(gal.)	300
Number of Axles	3
Engine Type:	DC-6V-92 EVE
Engine ID#:	6VF192394
Engine Displacement (cu. in.)	552
Number of Cylinders	6
Rated engine power (hp)	300
Rated Speed:(rpm)	2100
Fuel Type:	95% ETHNL 5%GAS
Oil Type:	40WT LOW ASH
Aftertreatment (Part. Traps or Catalysts):	N/A
Test Cycle	CBD Cycle

WVU Test Reference Number: ADM-92006-ETHNL
Fuel: 95% ETHNL 5%GAS Engine: DDC-6V-92 EVE Test Date: 6/21/93

Unit: g/mile

Test Serial No.	CO	NOx	CO2	mile/gal	BTU/mile
ADM-92006-ETHNL-01	124.8	18.2	3187	1.70	44793
ADM-92006-ETHNL-02	145.8	17.6	3079	1.73	43882
ADM-92006-ETHNL-03	141.4	18.0	3041	1.76	43262
ADM-92006-ETHNL-04	118.0	9.5	3229	1.68	45184
ADM-92006-ETHNL-05	116.0	18.8	3300	1.65	46147
ADM-92006-ETHNL-06	116.0	18.3	3341	1.63	46668
AVERAGE	127.0	18.2	3196	1.69	44989
Std. Dev.	13.3	0.44	119	0.05	1300
CV%	10.5%	2.39%	3.72%	2.88%	2.89%

OMHCE Components
Unit: g/mile

Test Serial No.	RHC	FIDHC	OMHC	HCHO	C2H5OH	CH3CHO
ADM-92006-ETHNL-01	9.6	19.6	24.3	0.64	21.2	2.53
ADM-92006-ETHNL-02	10.8	21.9	26.1	0.92	21.0	3.50
ADM-92006-ETHNL-03	9.7	19.8	24.6	0.68	21.6	2.47
ADM-92006-ETHNL-04	8.8	18.0	24.0	0.82	21.5	3.08
ADM-92006-ETHNL-05	8.9	18.5	26.2	0.76	24.6	3.32
ADM-92006-ETHNL-06	9.9	20.4	25.9	0.58	23.0	2.84
AVERAGE	9.6	19.7	25.2	0.76	22.2	2.96
Std. Dev.	0.74	1.40	0.98	0.11	1.39	0.42
CV%	7.67%	7.12%	3.89%	14.6%	6.25%	14.2%

Test Sequence Number: 160
WVU Test Reference Number: ADM-92004-ETHNL

Agency:	ADM TRUCKING
Contact Person:	SAM RICHARDSON
Telephone Number:	(217)-424-2651
Vehicle Type (Bus/Truck):	TRACTOR
Vehicle Serial Number:	4V1YDBUE4NN649451
Vehicle Manufacturer:	WHITE GMC
Vehicle's Model Year:	1992
Gross Vehicle Weight Rating (GVWR-lbs)	80000
Vehicle Curb Weight (lbs)	23688
Vehicle Seating Capacity	2
Vehicle Standing Capacity	0
Vehicle Testing Weight (lbs)	40000
Odometer Reading (miles)	97640 (ODOMETER)
Transmission Type: Auto/Manual	MANUAL
Transmiss. Config.:	9-SPEED
Outside Tire Dia.(in.)	43.43
Frontal Area of Vehicle (sq. ft.)	68.0
Tailpipe O.D.(in.)	5"
Fuel Tank(s) Capac.(gal.)	300
Number of Axles	3
Engine Type:	DDC 6V-92TA-TWAC
Engine ID#:	06VF192385
Engine Displacement (cu. in.)	552
Number of Cylinders	6
Rated engine power (hp)	300
Rated Speed:(rpm)	2100
Fuel Type:	95% ETHNL 5%GAS
Oil Type:	40WT LOW ASH
Aftertreatment (Part. Traps or Catalysts):	N/A
Test Cycle	CBD Cycle

WVU Test Reference Number: ADM-92004-ETHNL
Fuel: 95% ETHNL 5%GAS Engine: DDC 6V-92TA-TWAC Test Date: 6/22/93

Unit: g/mile

Test Serial No.	CO	NOx	CO2	mile/gal	BTU/mile
ADM-92004-ETHNL-02	97.7	31.5	2930	1.85	41104
ADM-92004-ETHNL-03	107.7	34.9	2906	1.85	41013
ADM-92004-ETHNL-04	90.2	23.4	2908	1.89	40298
ADM-92004-ETHNL-05	107.9	24.0	3713	1.48	51250
ADM-92004-ETHNL-06	95.6	18.7	2918	1.86	40791
AVERAGE	102.2	26.5	3075	1.79	40802
Std. Dev.	6.53	6.6	357	0.17	360
CV%	6.39%	24.8%	11.6%	9.62%	0.88%

OMHCE Components
Unit: g/mile

Test Serial No.	RHC	FIDHC	OMHC	HCHO	C2H5OH	CH3CHO
ADM-92004-ETHNL-02	10.0	20.8	28.5	0.68	28.0	2.05
ADM-92004-ETHNL-03	10.6	21.9	29.2	0.66	28.0	2.21
ADM-92004-ETHNL-04	10.4	20.8	N/A	0.55	N/A	2.10
ADM-92004-ETHNL-05	N/A	N/A	23.9	0.68	24.8	2.61
ADM-92004-ETHNL-06	8.7	18.1	26.4	0.72	25.9	2.79
AVERAGE	9.9	20.4	27.0	0.66	26.7	2.35
Std. Dev.	0.87	1.64	2.40	0.06	1.59	0.33
CV%	8.81%	8.03%	8.89%	9.75%	5.95%	14.0%

Test Sequence Number: 161
WVU Test Reference Number: ADM-92010-2D

Agency:	ADM TRUCKING
Contact Person:	SAM RICHARDSON
Telephone Number:	(217)-424-2651
Vehicle Type (Bus/Truck):	TRACTOR
Vehicle Serial Number:	4VY1YDBUEXNN649454
Vehicle Manufacturer:	WHITE GMC
Vehicle's Model Year:	1992
Gross Vehicle Weight Rating (GVWR-lbs)	80000
Vehicle Curb Weight (lbs)	23688
Vehicle Seating Capacity	2
Vehicle Standing Capacity	0
Vehicle Testing Weight (lbs)	40000
Odometer Reading (miles)	142747 (ODOMETER)
Transmission Type: Auto/Manual	MANUAL
Transmiss. Config.:	FULLER RTX-126098
Outside Tire Dia.(in.)	43.29
Frontal Area of Vehicle (sq. ft.)	68.0
Tailpipe O.D.(in.)	5"
Fuel Tank(s) Capac.(gal.)	300
Number of Axles	3
Engine Type:	DDC 6V-92TA
Engine ID#:	06VF192159
Engine Displacement (cu. in.)	552
Number of Cylinders	6
Rated engine power (hp)	300
Rated Speed:(rpm)	2100
Fuel Type:	#2 DIESEL
Oil Type:	40WT LOW ASH
Aftertreatment (Part. Traps or Catalysts):	N/A
Test Cycle	CBD Cycle

WVU Test Reference Number: ADM-92010-2D
Fuel: #2 DIESEL **Engine:** DDC 6V-92TA **Test Date:** 6/22/93

Unit: g/mile

Test Serial No.	CO	NOx	HC	PM	CO2	mile/gal	BTU/mile
ADM-92010-2D-02	N/A	34.0	3.1	1.90	3196	2.73	42818
ADM-92010-2D-03	N/A	32.9	3.6	2.48	3103	2.80	41725
ADM-92010-2D-04	N/A	33.1	3.5	1.80	3075	2.85	41098
AVERAGE	N/A	33.3	3.40	2.06	3125	2.79	41880
Std. Dev.	N/A	0.59	0.26	0.37	63	0.06	870
CV%	N/A	1.76%	7.78%	17.8%	2.03%	2.16%	2.08%

Appendix 3

West Virginia University
Transportable Heavy-Duty Vehicle
Emissions Testing Laboratory

Test Results Report
June 1994

WEST VIRGINIA UNIVERSITY

TRANSPORTABLE HEAVY DUTY VEHICLE EMISSIONS TESTING LABORATORY

Test Results Report

For

Archer Daniel Midland Trucking
Decator, IL

(Year 1994)

Department of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26506
Phone: (304) 293-3111
FAX: (304) 293-6689

June, 1994

TRANSPORTABLE HEAVY DUTY VEHICLE EMISSIONS TESTING LABORATORY

Conducted by:

Department of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26506-6101
Phone: (304) 293-3111
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G. Michael Palmer

Lab Manager:

Byron Rapp

Report Prepared by:

Wenguang Wang

Sponsored by:

U.S. Department of Energy (DOE)
Office of Transportation Technologies
Office of Alternative Fuels - Fuel Utilization Data and Analysis
Program Manager: John Garbak

The West Virginia University (WVU) Transportable Heavy-Duty Vehicle Emissions Testing Laboratory traveled from Morgantown, West Virginia to Peoria, Illinois and tested 3 vehicles belonging to the Archer Daniel Midland Trucking on Apr. 13 - 28, 1994.

The test and calibration procedures of Code 40 of the Federal register (CFR-40), relevant to chassis testing, were followed whenever applicable.

Two driving cycles were used in testing the three trucks. First, the three vehicles were tested over the modified CBD driving cycle which is being called as the Truck-CBD cycle (Fig.1) in the NREL database. The Truck-CBD cycle consists of fourteen identical segments. Each segment includes 30 seconds of acceleration, 5 seconds of 20 mph cruise, 15 seconds of deceleration and 10 seconds of idle in gear. The driving time and distance of the cycle is 850 seconds and 2 miles. Second, the vehicles were tested over the five peak (5PK) driving cycle which is being called as the WVU-Truck cycle (Fig.2) in the NREL database. The cycle was developed by the West Virginia University (WVU) as a general representation of the acceleration, cruise and deceleration modes encountered in a typical truck operation. The cycle consists of five segments with different cruise speeds such as 20, 25, 30, 35, and 40 mph respectively. Each of the five segments has a different acceleration time such as 25.1, 32.4, 40.6, 49.4, and 59.4 seconds corresponding to the respective increasing order of top speeds. The cruise and idle time are 84.6 seconds and 15 seconds for all the five segments. Whereas, the deceleration time for the five segments is 15, 18.7, 22.5, 26.2, and 30 seconds at their respective top speeds. The total driving time and distance of the cycle is 850 seconds and 5 miles. During the emission test, a trace of the drive cycle is displayed on a video monitor in the driver's area. The driver follows the cycle and his driving pattern is displayed on the same monitor.

The exhaust gas emissions were measured using the following analyzers: non-dispersive infrared analyzer (NDIR) for Carbon Monoxide (CO) and carbon dioxide (CO_2); chemiluminescent detector (CLD) for Oxides of Nitrogen (NO_x); and heated flame ionization detector (FID) for total hydrocarbon emissions. Particulate matter (PM) was measured by using a double dilution exhaust sample drawn over 70-mm fluorocarbon coated glass fiber filters for gravimetric analysis.

For alcohol fueled vehicles, the unburned methanol or ethanol in the exhaust was sampled by continuously bubbling a sample of diluted exhaust through impingers filled with deionized water. Silica cartridges coated with a 2,4 dinitrophenyhydrazine (DNPH) were used to measure the carbonyl compounds in the exhaust. The organic material hydrocarbon equivalent mass (OMHCE) emissions were also calculated.

The following test procedures have been adopted:

(1) Position and mount the test vehicle onto the test bed.

(2) Conduct a warm-up cycle to stabilize the dynamometer transmission system to 38°C.

(3) Cool down (soak) for 20 minute period.

(4) Operate specified test cycle.

(5) Process emissions data and initiate soak period (step 3) if further testing is required.

(6) Repeat steps (3) through (5) as required.

Typically three to six repetitive tests were conducted and the test results are reported for the individual test run and for the average of the tests. Both continuous sampling and bag sampling were employed. All data are reported in grams per mile (gm/mi).

NOTE: This test data should not be compared with the 1990 Clean Air Act emissions standard that used FTP for urban busses and trucks, which is given in grams per brake horsepower (gm/bhp), which is different from the Chassis Dynamometer test data reported here.

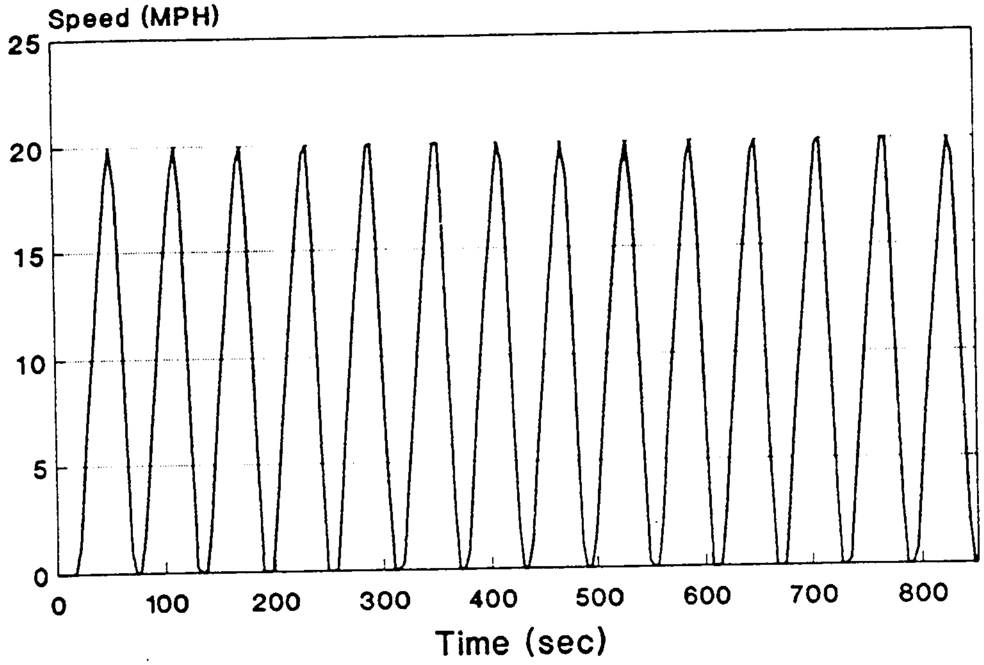

Figure 1 **Truck-CBD Cycle**

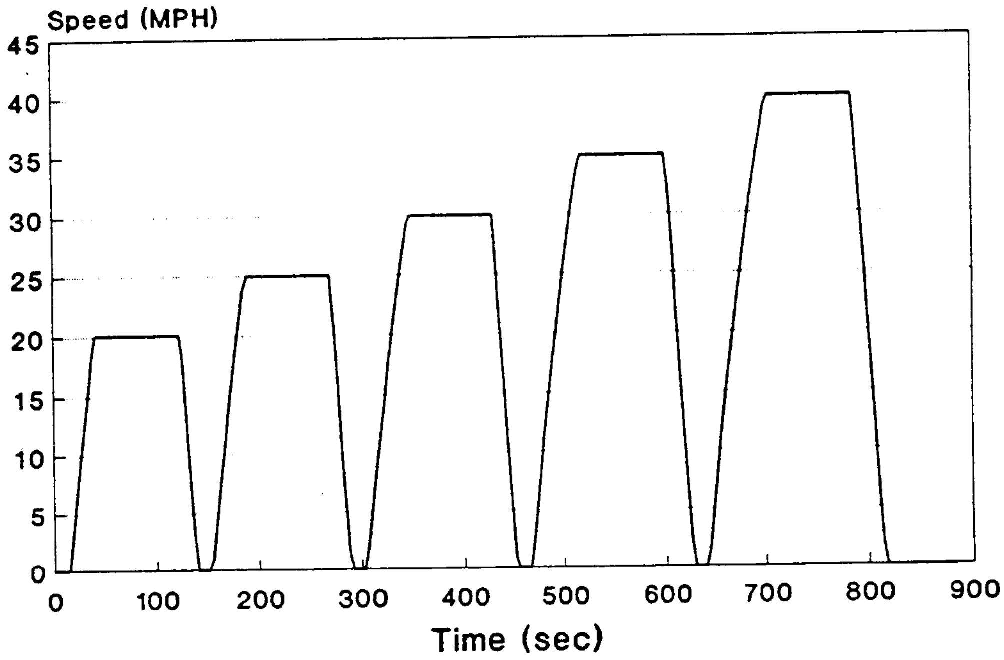

Figure 2 **WVU-Truck Cycle**

Symbols or Abbreviations in the report

Test Sequence Number	= Unique number assigned to each test with the date order
WVU Test Reference Number	= Unique number assigned to each test, including the fleet owner abbreviated name, vehicle number, fuel and aftertreatment if any
Gross Vehicle Weight	= Maximum legal weight at which the vehicle can be operated (GVW)
Simulated Weight	= Inertial weight created by dynamometer flywheels to simulate test weight
Test Cycle	= Driving pattern of the test
Run Seq. No.	= The first three digits stand for test sequence number and the last two digits stand for repeat run number
HC	= Total hydrocarbons for non-alcohol fuel in exhaust
CO	= Carbon monoxide in exhaust
NOx	= Oxides of nitrogen in exhaust
PM	= Particulate matter in exhaust
CO_2	= Carbon dioxide in exhaust
OMHCE	= Organic material hydrocarbon equivalent in exhaust
CH_3OH	= Methanol in exhaust
C_2H_5OH	= Ethanol in exhaust
HCHO	= Formaldehyde in exhaust
CH_3CHO	= Acetaldehyde in exhaust
FID-HC	= Total hydrocarbons measured by FID
RHC	= Residual Hydrocarbon (= FIDHC - r $\times$ CH_3OH), r is FID response to CH_3OH
Mile/Gal	= Fuel economy calculated by carbon balance method. For CNG, it is assumed that 137 ft^3 at STP is equal to 1 gallon of #1 diesel.
Btu/mile	= Energy supply per mile

Test Schedule for Archer Daniel Midland at Peoria, IL (1994)

Test Sequence Number	WVU Test Reference Number	Test Date	Vehicle Type	Vehicle Fleet Number	Engine Type	Fuel Type
275	ADM-92006-E95-TCBD	04-22-1994	Tractor	92006	6V-92TA-EVE	E95
276	ADM-92006-E95-TRK	04-22-1994	Tractor	92006	6V-92TA-EVE	E95
278	ADM-92004-E95-TCBD	04-25-1994	Tractor	92004	6V-92TA-TWAC	E95
279	ADM-92004-E95-TRK	04-26-1994	Tractor	92004	6V-92TA-TWAC	E95
280	ADM-92010-D2-TCBD	04-26-1994	Tractor	92010	6V-92TA-EVE	D2
281	ADM-92010-D2-TRK	04-27-1994	Tractor	92010	6V-92TA-EVE	D2

Test Sequence Number: 275
WVU Test Reference Number: ADM-92006-E95-TCBD

Fleet Owner Full Name	Archer Daniel Midland Trucking
Fleet Address	2501 N Brush College Rd
Fleet Address City State	Decator, IL
Vehicle Type	TRACTOR
Vehicle ID Number (VIN)	4V1YDBUE6NN649452
Vehicle Manufacturer	WHITE/GM
Vehicle Model Year	1992
Gross Vehicle Weight (GVW) (lb)	80000
Vehicle Total Curb Weight (lb)	
Vehicle Simulated Weight (lb)	42017
Odometer Reading (mile)	173280
Transmission Type	MANUEL
Transmission Configuration	9-SPEED
Number of Axles	3
Engine Type	DDEC-6V92-EVE
Engine ID Number	6VF192394
Engine Displacement in Liters	552
Number of Cylinders	6
Engine Rated Power (hp)	300 HP
Primary Fuel	E95
Primary Fuel ID	N-WV-1162
Secondary Fuel	N/A
Secondary Fuel ID	N/A
Particulate Trap Manufacture	N/A
Catalytic Converter Manufacture	N/A
Test Cycle	Truck CBD
Test Date	04-23-1994

Unit: g/mile

Test Serial No.	CO	NOx	PM	CO2	mile/gal	BTU/mile
275-1	26.6	18.6	0.48	4568	1.26	60546
275-2	28.4	19.0	0.33	4722	1.21	62682
275-3	28.2	18.4	0.43	4692	1.22	62224
275-4	33.1	18.0	0.39	4702	1.22	62484
275 AVERAGE	27.7	18.5	0.41	4671	1.23	61984
Std. Dev.	1.0	0.4	0.06	70	0.02	977
CV%	3.56%	2.25%	**	1.49%	1.81%	1.58%

Test Serial No.	RHC	FID-HC	OMHC	HCHO	C2H5OH	CH3CHO
275-1	N/A	13.26	19.82	0.47	20.27	N/A
275-2	7.58	15.75	22.33	0.52	22.12	1.88
275-3	7.50	15.49	20.84	0.49	19.71	1.97
275-4	7.90	16.29	21.82	0.54	20.60	2.01
275 AVERAGE	7.66	15.84	21.20	0.50	20.67	1.95
Std. Dev.	0.21	0.41	1.11	0.03	1.03	0.07
CV%	2.76%	2.58%	5.23%	6.16%	4.99%	3.41%

** The average and standard deviation are very small (No significant meaning for CV%).

Test Sequence Number: 276
WVU Test Reference Number: ADM-92006-E95-TRK

Fleet Owner Full Name	Archer Daniel Midland Trucking
Fleet Address	2501 N Brush College Rd
Fleet Address City State	Decator, IL
Vehicle Type	TRACTOR
Vehicle ID Number (VIN)	4V1YDBUE6NN649452
Vehicle Manufacturer	WHITE/GM
Vehicle Model Year	1992
Gross Vehicle Weight (GVW) (lb)	80000
Vehicle Total Curb Weight (lb)	
Vehicle Simulated Weight (lb)	42017
Odometer Reading (mile)	173290
Transmission Type	MANUEL
Transmission Configuration	9-SPEED
Number of Axles	3
Engine Type	DDEC-6V92-EVE
Engine ID Number	6VF192394
Engine Displacement in Liters	552
Number of Cylinders	6
Engine Rated Power (hp)	300 HP
Primary Fuel	E95
Primary Fuel ID	N-WV-1162
Secondary Fuel	N/A
Secondary Fuel ID	N/A
Particulate Trap Manufacture	N/A
Catalytic Converter Manufacture	N/A
Test Cycle	WVU-Truck
Test Date	04-23-1994

Unit: g/mile

Test Serial No.	CO	NOx	PM	CO2	mile/gal	BTU/mile
276-01	14.6	14.9	0.34	2779	2.07	36722
276-02	N/A	14.3	0.24	2787	2.06	36909
276-03	16.9	14.5	0.34	2765	2.08	36564
276-04	N/A	14.1	0.15	2781	2.07	36680
276 AVERAGE	15.8	14.4	0.27	2778	2.07	36719
Std. Dev.	1.2	0.3	0.09	9	0.01	143
CV%	7.30%	2.36%	**	0.34%	0.39%	0.39%

Test Serial No.	RHC	FID-HC	OMHC	HCHO	C2H5OH	CH3CHO
276-01	3.61	7.45	10.02	0.23	9.39	1.02
276-02	3.46	7.15	9.91	0.25	9.48	1.00
276-03	3.54	7.28	9.64	0.25	8.80	1.08
276-04	3.36	6.97	9.95	0.22	9.50	N/A
276 AVERAGE	3.49	7.21	9.88	0.24	9.29	1.03
Std. Dev.	0.11	0.20	0.17	0.02	0.33	0.04
CV%	3.08%	2.82%	1.68%	6.32%	3.57%	4.03%

** The average and standard deviation are very small (No significant meaning for CV%).

Test Sequence Number: 278
WVU Test Reference Number: ADM-92004-E95-TCBD

Fleet Owner Full Name	Archer Daniel Midland Trucking
Fleet Address	2501 N Brush College Rd
Fleet Address City State	Decator, IL
Vehicle Type	TRACTOR
Vehicle ID Number (VIN)	4V1YDBUE4NN649451
Vehicle Manufacturer	WHITE/GM
Vehicle Model Year	1992
Gross Vehicle Weight (GVW) (lb)	80000
Vehicle Total Curb Weight (lb)	
Vehicle Simulated Weight (lb)	42080
Odometer Reading (mile)	137545
Transmission Type	MANUEL
Transmission Configuration	9-SPEED
Number of Axles	3
Engine Type	DDEC-6V92-TWAC
Engine ID Number	06VF192385
Engine Displacement in Liters	552
Number of Cylinders	6
Engine Rated Power (hp)	300 HP
Primary Fuel	E95
Primary Fuel ID	N-WV-1162
Secondary Fuel	N/A
Secondary Fuel ID	N/A
Particulate Trap Manufacture	N/A
Catalytic Converter Manufacture	N/A
Test Cycle	Truck CBD
Test Date	04-25-1994

Unit: g/mile

Test Serial No.	CO	NOx	PM	CO2	mile/gal	BTU/mile
278-1	45.4	14.0	0.69	3807	1.49	50973
278-2	34.7	14.4	0.65	3737	1.52	49889
278-3	31.6	14.5	0.59	3714	1.54	49501
278-4	N/A	13.5	0.59	3736	1.51	50451
278-5	40.6	13.8	0.76	3723	1.53	49747
278 AVERAGE	38.1	14.0	0.66	3743	1.52	50112
Std. Dev.	6.1	0.4	0.07	37	0.02	594
CV%	16.14%	2.96%	**	0.98%	1.27%	1.19%

Test Serial No.	RHC	FID-HC	OMHC	HCHO	C2H5OH	CH3CHO
278-1	6.18	12.78	18.04	0.71	16.58	2.45
278-2	6.51	13.50	19.30	0.64	18.21	2.42
278-3	6.30	13.06	18.52	0.60	17.41	2.30
278-4	6.57	13.45	17.45	0.77	15.00	2.36
278-5	5.99	12.36	17.04	0.63	15.67	2.09
278 AVERAGE	6.31	13.03	18.07	0.67	16.57	2.32
Std. Dev.	0.24	0.48	0.89	0.07	1.29	0.14
CV%	3.78%	3.66%	4.92%	**	7.79%	6.15%

** The average and standard deviation are very small (No significant meaning for CV%).

Test Sequence Number: 279
WVU Test Reference Number: ADM-92004-E95-TRK

Fleet Owner Full Name	Archer Daniel Midland Trucking
Fleet Address	2501 N Brush College Rd
Fleet Address City State	Decator, IL
Vehicle Type	TRACTOR
Vehicle ID Number (VIN)	4V1YDBUE4NN649451
Vehicle Manufacturer	WHITE/GM
Vehicle Model Year	1992
Gross Vehicle Weight (GVW) (lb)	80000
Vehicle Total Curb Weight (lb)	
Vehicle Simulated Weight (lb)	42080
Odometer Reading (mile)	137561
Transmission Type	MANUEL
Transmission Configuration	9-SPEED
Number of Axles	3
Engine Type	DDEC-6V92-TWAC
Engine ID Number	06VF192385
Engine Displacement in Liters	552
Number of Cylinders	6
Engine Rated Power (hp)	300 HP
Primary Fuel	E95
Primary Fuel ID	N-WV-1162
Secondary Fuel	N/A
Secondary Fuel ID	N/A
Particulate Trap Manufacture	N/A
Catalytic Converter Manufacture	N/A
Test Cycle	WVU-Truck
Test Date	04-26-1994

Unit: g/mile

Test Serial No.	CO	NOx	PM	CO2	mile/gal	BTU/mile
279-01	20.4	13.0	0.22	2018	2.82	26937
279-02	21.3	12.9	0.14	2004	2.84	26792
279-03	23.1	12.5	0.13	2006	2.83	26839
279-04	26.4	12.5	0.37	1995	2.84	26769
279-05	25.4	12.3	0.13	1990	2.85	26664
279 AVERAGE	23.3	12.6	0.20	2003	2.84	26800
Std. Dev.	2.6	0.3	0.10	11	0.01	100
CV%	11.03%	2.35%	**	0.54%	0.40%	0.37%

Test Serial No.	RHC	FID-HC	OMHC	HCHO	C2H5OH	CH3CHO
279-01	3.53	7.24	9.26	0.28	8.35	0.90
279-02	3.63	7.44	9.59	0.29	8.64	0.98
279-03	3.51	7.18	9.22	0.29	8.20	1.01
279-04	3.66	7.48	9.36	0.34	8.07	1.07
279-05	3.45	7.08	9.19	0.32	8.15	1.08
279 AVERAGE	3.56	7.28	9.32	0.30	8.28	1.01
Std. Dev.	0.09	0.17	0.16	0.03	0.22	0.07
CV%	2.45%	2.35%	1.74%	8.26%	2.71%	7.27%

** The average and standard deviation are very small (No significant meaning for CV%).

Test Sequence Number: 280
WVU Test Reference Number: ADM-92010-D2-TCBD

Fleet Owner Full Name	Archer Daniel Midland Trucking
Fleet Address	2501 N Brush College Rd
Fleet Address City State	Decator, IL
Vehicle Type	TRACTOR
Vehicle ID Number (VIN)	4V1YDBUE4NN649451
Vehicle Manufacturer	WHITE/GM
Vehicle Model Year	1992
Gross Vehicle Weight (GVW) (lb)	80000
Vehicle Total Curb Weight (lb)	
Vehicle Simulated Weight (lb)	41953
Odometer Reading (mile)	220672
Transmission Type	MANUEL
Transmission Configuration	9-SPEED
Number of Axles	3
Engine Type	DDEC-6V92-EVE
Engine ID Number	06VF192385
Engine Displacement in Liters	552
Number of Cylinders	6
Engine Rated Power (hp)	300 HP
Primary Fuel	D2
Primary Fuel ID	N-WV-1164
Secondary Fuel	N/A
Secondary Fuel ID	N/A
Particulate Trap Manufacture	N/A
Catalytic Converter Manufacture	N/A
Test Cycle	Truck CBD
Test Date	04-26-1994

Unit: g/mile

Test Serial No.	CO	NOx	HC	PM	CO2	mile/gal	BTU/mile
280-01	6.9	21.4	3.9	1.35	3072	2.87	40832
280-02	9.3	21.2	3.6	1.42	3018	2.91	40152
280-03	7.9	20.7	3.4	1.40	3112	2.83	41369
280-04	8.5	21.5	3.5	1.45	3053	2.88	40598
280 AVERAGE	8.1	21.2	3.6	1.40	3064	2.87	40738
Std. Dev.	1.0	0.4	0.2	0.04	39	0.03	507
CV%	12.41%	1.68%	6.00%	2.99%	1.28%	1.15%	1.24%

Test Sequence Number: 281
WVU Test Reference Number: ADM-92010-D2-TRK

Fleet Owner Full Name	Archer Daniel Midland Trucking
Fleet Address	2501 N Brush College Rd
Fleet Address City State	Decator, IL
Vehicle Type	TRACTOR
Vehicle ID Number (VIN)	4V1YDBUE4NN649451
Vehicle Manufacturer	WHITE/GM
Vehicle Model Year	1992
Gross Vehicle Weight (GVW) (lb)	80000
Vehicle Total Curb Weight (lb)	
Vehicle Simulated Weight (lb)	41953
Odometer Reading (mile)	220698
Transmission Type	MANUEL
Transmission Configuration	9-SPEED
Number of Axles	3
Engine Type	DDEC-6V92-EVE
Engine ID Number	06VF192385
Engine Displacement in Liters	552
Number of Cylinders	6
Engine Rated Power (hp)	300 HP
Primary Fuel	D2
Primary Fuel ID	N-WV-1164
Secondary Fuel	N/A
Secondary Fuel ID	N/A
Particulate Trap Manufacture	N/A
Catalytic Converter Manufacture	N/A
Test Cycle	WVU-Truck
Test Date	04-27-1994

Unit: g/mile

Test Serial No.	CO	NOx	HC	PM	CO2	mile/gal	BTU/mile
281-01	3.7	19.2	1.7	0.82	1808	4.87	24006
281-02	4.3	19.1	1.7	0.71	1729	5.09	22970
281-02	4.4	18.5	1.7	0.85	1815	4.85	24107
281-04	3.9	18.5	1.7	0.76	1792	4.92	23793
281 AVERAGE	4.1	18.8	1.7	0.78	1786	4.93	23719
Std. Dev.	0.3	0.4	0.0	0.06	39	0.11	516
CV%	8.11%	2.01%	0.00%	7.96%	2.19%	2.21%	2.18%

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13. ABSTRACT *(Maximum 200 words)* This report presents the results of an ethanol heavy-duty truck demonstration project. The four trucks were equipped with specially modified Detroit Diesel Corporation engines and ran on E95 (95% ethanol and 5% light hydrocarbon denaturant). They were owned and operated by Archer Daniels Midland Trucking, Incorporated, and were used almost every day for deliveries to points in Illinois, Indiana, Iowa, and Missouri. As a result of this project, a considerable amount of data was recorded, for the first time, on the performance, durability, economics, and emissions of heavy-duty trucks running on ethanol.

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