Alternative Fuel TRUCKS

Case Studies

Running Line-Haul Trucks on Ethanol

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One of Archer Daniels Midland's ethanol-powered line-haul trucks

Imagine driving a 55,000-pound tractor-trailer that runs on corn! If you find it difficult to imagine, you can ask the truck drivers for Archer Daniels Midland (ADM) what it's like. For the past 4 years, they have been piloting four trucks powered by ethyl alcohol, or "ethanol," derived from corn.

Several advantages to operating trucks on ethanol rather than on conventional petroleum diesel fuel present themselves. Because ethanol can be produced domestically, unlike most of our petroleum supply, the price and supply of ethanol is not subject to the whims of potentially unstable foreign governments. And domestic production translates into domestic jobs. In addition, ethanol has the potential to reduce harmful emissions, such as particulate matter and oxides of nitrogen (NO_X), that are now emitted by diesel trucks. Finally, ethanol can minimize net emissions of carbon dioxide—a gas that adds to global warming, or the greenhouse effect. Corn and other biomass sources absorb carbon dioxide from the atmosphere as they grow. The carbon dioxide is then released into the atmosphere when ethanol made from the biomass is burned as fuel. The next

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a U.S. DOE national laboratory

crop of plants completes the cycle by absorbing carbon dioxide back out of the atmosphere.

The ADM project was designed to test the feasibility of using ethanol to power large line-haul trucks. The project was funded by the U.S. Department of Energy (DOE) through the National Renewable Energy Laboratory (NREL), and managed by the Illinois Department of Commerce and Community Affairs (DCCA). Since February 1992, the Alternative Fuels Data Center at NREL has logged data on the fuel use and maintenance requirements of the ethanol trucks as well as similar diesel-powered trucks for comparison. This case study outlines some of the project's findings. A more detailed report on the project is available from the National Alternative Fuels Hotline or NREL's World Wide Web site (see back page for numbers and addresses).

Fuel Economy and Range

Ethanol is the type of alcohol contained in alcoholic beverages, but when it is used as a beverage, it is highly taxed. To avoid this tax when using ethanol as a fuel, some gasoline is added to the ethanol, which makes it poisonous as a beverage. In addition, a small quantity of a lubricant, called Lubrizol, was added to the ethanol used in the ADM trucks—necessary because ethanol is naturally less lubricating than conventional diesel fuel, which is an oil.

By nature of its chemical structure, ethanol contains less energy per gallon than conventional diesel fuel. A gallon of pure ethanol will release about 75,600 British thermal units (Btu) when burned completely. The fuel used in the ADM trucks, which is 95% ethanol and 5% gasoline (known as "E95"), will release about 77,600 Btu per gallon. In contrast, diesel fuel will release about 129,000 Btu per gallon. This means that about 1.7 gallons of E95 have the same energy content as a gallon of diesel fuel. The quantity of an alternative fuel that has the same energy content of a gallon of diesel fuel is often called a diesel-equivalent gallon.

Figure 1 shows the average fuel economy of the four ethanol trucks, along with the fuel economy of a comparable diesel-powered ADM truck. The fuel economies are presented in miles per diesel-equivalent gallon, which allows for a direct comparison between the ethanol and diesel trucks. The average fuel economy of the ethanol trucks has been about 8% less than that of the diesel truck, a difference that probably results from the changes in the engine required to allow it to run on ethanol.

About Ethanol

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Ethanol is an alcohol derived from biomass such as corn, sugar cane, grasses, trees, and agricultural waste. It is made directly by fermenting the sugars contained in the biomass. It can also be produced biochemically by using enzymes to break down cellulose to form glucose, which is then fermented. The potential domestic resource base for ethanol is vast.

For use in vehicles, ethanol is usually blended with gasoline or other fuels. It can be used as a neat or near-neat fuel (95% or 85% ethanol) in dedicated light-duty and heavy engines that run on only one fuel (as it was used in the ADM trucks). It can be combined with gasoline in any ratio when it is used in flexible-fuel vehicles. Or it can be added to gasoline in small quantities (up to 10%) as an oxygenate and burned in conventional gasoline cars to reduce emissions. Ethanol can also be used to produce ethers such as ethyl tertiary butyl ether (ETBE) that can be blended with petroleum fuels or used independently.

The ethanol engines are of the same two-stroke, compression ignition design as the diesel engines used as the basis for comparison in this project. However, several changes were made to the engines so they could run on ethanol—changing the electronic control system, enlarging the holes in the fuel injectors, adding a glow plug to assist ignition during cold starts, and increasing the compression ratio (from 18:1 for diesel) to 23:1 for ethanol. The increased compression ratio may account for much of the difference in fuel economy. At low compression ratios, an increase in compression ratio generally increases fuel economy. However, above a compression ratio of around 16:1, raising the compression ratio generally lowers fuel economy because of increased friction forces. The high compression ratio is required to ignite the ethanol because its lower cetane number leads to difficulty in autoignition.

Because ethanol has a lower energy content than diesel fuel, ethanol trucks would require larger fuel tanks to achieve the same range between refuelings as a diesel truck. However, for the ADM ethanol trucks, fuel tanks the same size as their diesel trucks (two 120-gallon fuel tanks) gave the ethanol trucks a range of about 780 miles, which was more than sufficient for their daily driving route.

Because ethanol is a liquid fuel that uses a dispensing system nearly identical to diesel fuel, refueling the trucks was quick and easy.

Refueling with ethanol is as quick and easy as refueling with diesel.

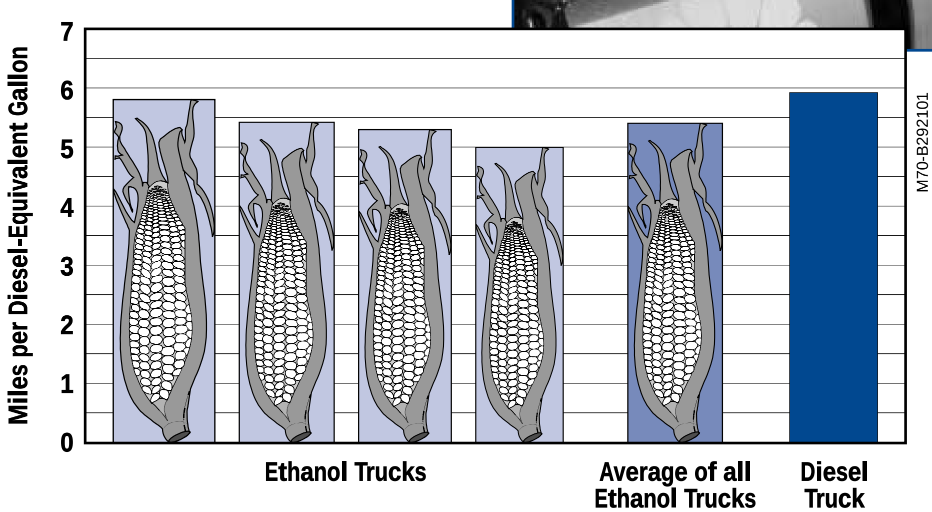

Figure 1. *Average fuel economy of the ADM trucks*

Cost

The cost of the fuel represents about 20% of the overall cost of owning and operating a heavy truck. This fuel cost is strongly affected by state and federal taxes. In operating its ethanol trucks, ADM benefited from the Federal Alcohol Tax Credit, which allows a $0.54 per gallon income tax credit for 100% ethanol. Because ADM used E95, its tax credit was $0.513 per gallon, bringing its average fuel cost to about $0.67 per gallon of E95. As shown in the adjoining table, this tax credit and the difference in state and federal tax rates led to an E95 fuel that costs nearly the same per gallon as diesel fuel. The E95 fuel was about 75 cents per diesel-equivalent gallon more expensive than diesel fuel.

The fuel cost per mile traveled depends on both the fuel cost and the fuel economy of the trucks. On the average, the fuel cost for the E95 trucks was about $0.32 per mile compared to $0.18 per mile for the diesel trucks.

In addition to the different fuel, fuel filters, oil, and oil filters for the ethanol trucks were different than those used on the diesel truck. The price of the oil was comparable to the oil used in the diesel truck, but the filters were significantly more expensive. The combination of primary and secondary fuel filters for the ethanol trucks was about $115. The diesel fuel filters were about $6. The oil filters were about $23 each for the ethanol trucks versus $9 each for the diesel truck. The filters were changed at approximately the same intervals on the ethanol and diesel trucks. With so few ethanol trucks on the road, these filters are a specialty item that can demand a premium price.

Contributions to Fuel Cost for E95 Ethanol Fuel and Conventional Diesel Fuel
(dollars per gallon—parenthesis indicates a negative value)

	E95 Ethanol Fuel	Diesel Fuel
Average Base Cost	$1.18	$0.58
Federal Alcohol Tax Credit	($0.513)	n/a
Subtotal	$0.667	$0.58
State Motor Fuel Tax (Illinois)	$0.19	$0.19
Federal Motor Fuel Tax	$0.184	$0.2440
State Sales Tax (6.25%)	$0.0417	$0.0363
Total Cost per Liquid Gallon (excludes delivery charges and dealer profit)	$1.08	$1.05
Total Cost per Diesel-Equivalent Gallon	$1.80	$1.05

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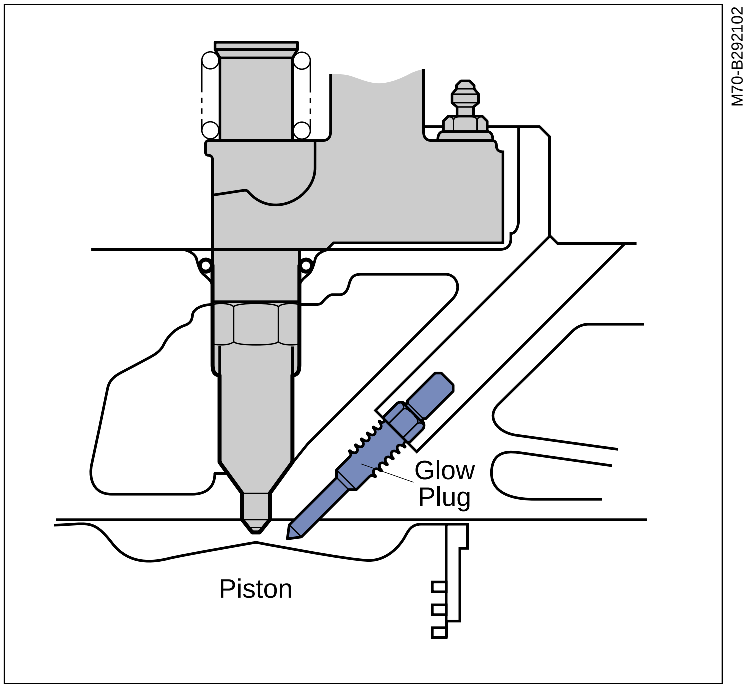
Maintenance and Repair Issues

The ADM experience proved the viability of using ethanol to power large, over-the-road trucks. One of ADM's ethanol trucks successfully logged more than 325,000 miles without a major engine overhaul. However, with any new technology some operational issues are inevitable—and Detroit Diesels Corporation's (DDC) ethanol engines were no exception.

Two main maintenance and repair issues related to the alcohol engines surfaced during this project: injector plugging and glow plug failure. Similar issues have arisen in other alcohol truck projects and engine manufacturers are working on solutions.

The problem with the fuel injectors was first discovered by the drivers, who reported low power and poor acceleration in the ethanol trucks. Installing a new set of injectors dramatically increased engine performance. Examination of the injector tips revealed fouling with a gummy, black deposit that restricted the fuel flow and the ability of the injector to atomize the fuel properly for complete combustion in the cylinder. The exact cause of the deposit is being investigated.

All six fuel injectors were replaced on each of the ADM ethanol trucks more than once. In all, 14 sets of injectors were used in the four trucks during the 3-year project. At almost $1000 per set, this represented a significant expense. The average life of the fuel injectors was about 60,000 miles, but the actual life varied considerably from about 19,000 miles to nearly 100,000 miles.



The ethanol engines use a glow plug to aid ignition during cold starts.

Because ethanol does not autoignite easily, a glow plug was installed in each cylinder to aid in starting the ethanol compression ignition engines. The glow plug is similar to a spark plug except that it provides a constant hot surface rather than an intermittent spark. The glow plugs were turned on for 1 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 burned out, or the tip of the plug broke off. Although these failures were relatively infrequent, they present a durability challenge that some engine manufacturers are actively working to overcome. Eleven of the 24 glow plugs in the ADM ethanol trucks were replaced during the 3-year project.

Cutaway of the DDC electronic unit injector

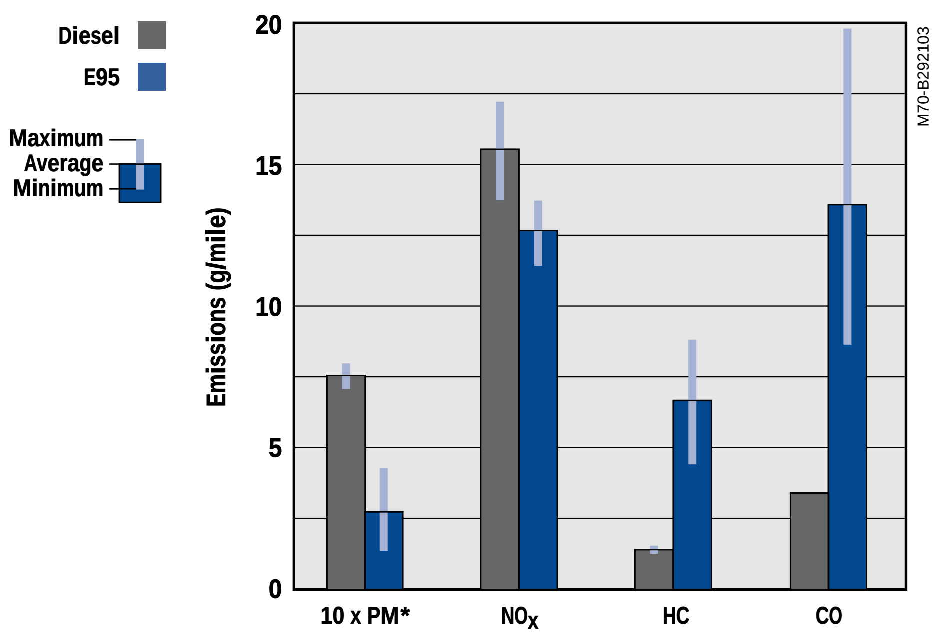
Emissions

The in-use emissions levels of heavy trucks can be approximated using a chassis dynamometer. The chassis dynamometer puts the whole vehicle through a specific driving cycle and measures the emissions from the tailpipe. Unfortunately, there is currently no accepted standard driving cycle for chassis dynamometer testing of heavy trucks. Although a standard cycle, called the Central Business District (CBD) cycle, is an accepted cycle for buses, many large trucks with manual transmissions are unable to accomplish the rapid accelerations and braking requirements of the CBD. Developing a more appropriate test cycle for heavy trucks is the object of several ongoing research projects. In the interim, West Virginia University (WVU) has designed a "5-peak" driving cycle that can be driven by most heavy trucks.

In 1995 and 1996, WVU tested the ADM trucks using the 5-peak test cycle. Figure 2 shows the average, minimum, and maximum emissions measured from the ADM trucks. The average particulate matter (PM) emissions measured from the ethanol trucks were less than half those from the diesel truck. The average NO_X emissions were marginally lower from the ethanol trucks than from the diesel trucks. Surprisingly, the average hydrocarbon (HC) and carbon monoxide (CO) emissions were higher from the ethanol trucks than they were from the diesel trucks.

Figure 2. Chassis dynamometer emissions results for the ADM trucks

* Particulate matter values were magnified 10 times to show results on the same scale.



The Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) require that new engines be emissions certified using standard procedures on engine (rather than chassis) dynamometer tests. During an engine dynamometer test, the engine is put on a test stand and run through specific loads and speeds while the exhaust emissions are measured. In January 1996, one of the ethanol engines was removed from an ADM truck and installed on an engine dynamometer to run this type of test. Figure 3 shows the results of the test compared to certification data for the diesel version of the same engine. The emissions results from engine dynamometer tests show the same trends as the chassis dynamometer tests: the ethanol engine produced less PM and NO_X emissions, but more HC and CO emissions.

In its evaluation of alternative fuel transit buses, NREL worked with WVU to investigate some high HC and CO emissions from ethanol-powered buses using the same engines as the ADM trucks. Several adjustments or repairs—changing the blower bypass valve settings, replacing old fuel injectors with new, and replacing the catalytic convertor—were performed on the high emitters. Tests showed that replacing the catalytic convertor reduced CO emissions by 85% and HC emissions

To Be Specific....

Here are the specifications for the ADM ethanol trucks:

Chassis:	White/GMC WIM64T Class 8 line-haul tractor
Fuel:	95% ethanol (ethyl alcohol) 5% gasoline; Lubrizol added to improve lubrication (0.06%)
Curb weight Gross vehicle weight rating:	23,688 pounds 80,000 pounds
Engine:	1992 Detroit Diesel Corporation 6V92
Displacement:	552 in.^{3} (9.05 liters)
Power:	300 horsepower at 2100 revolutions per minute (rpm)
Torque:	975 foot-pounds at 1200 rpm
Fuel tanks:	Two 120-gallon stainless steel tanks
Capacity:	Equivalent to 144 gallons of diesel

by 67%. Reports on NREL's Alternative Fuel Transit Bus program and on this emissions testing work are available from the Alternative Fuels Hotline or NREL's World Wide Web site (see back page for phone numbers and addresses).

Both the engine and chassis dynamometer tests have shown that ethanol engines have the potential to sub-stantially reduce emissions, but emissions are also highly dependent on the engine technology and the vehicle's condition.

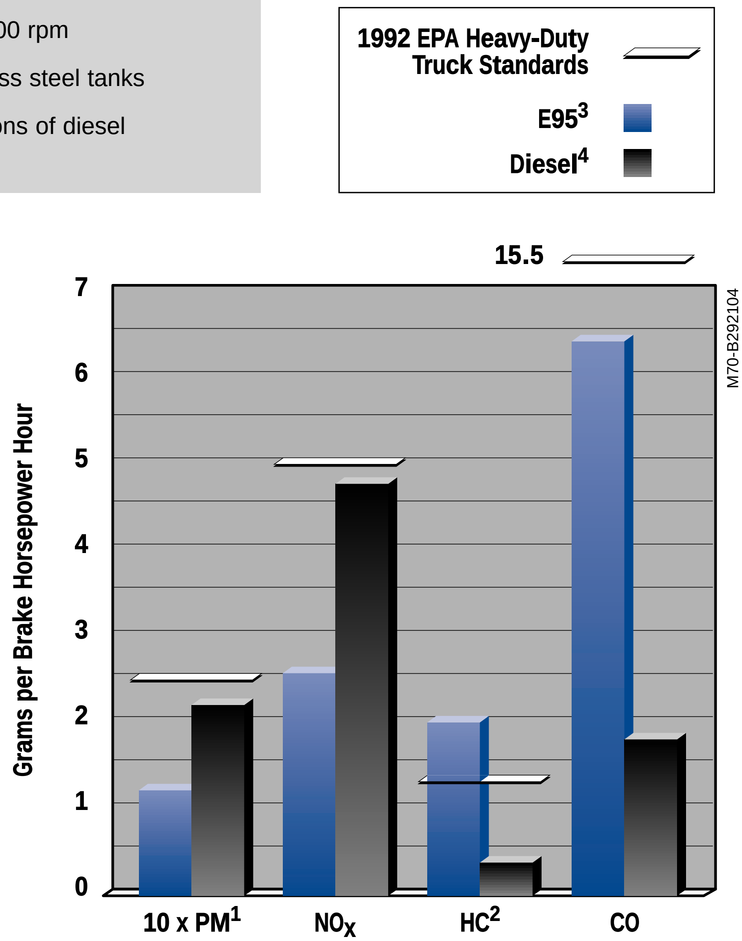


Figure 3. Ethanol and diesel DDC 6V92 engine dynamometer emissions data

1 PM values were magnified 10 times to show results on the same scale.
2 Total HC for diesel, organic matter hydrocarbon equivalent (OMHCE) for ethanol
3 ADM ethanol engine tested by the Southwest Research Institute after 325,000 miles of service
4 1993 EPA certification data

ADM's four ethanol trucks logged more than 1,200,000 miles.

Where Do We Go From Here?

The ADM project and others like it have demonstrated that ethanol can be successfully used to power large trucks. Technical issues do remain, but they are not insurmountable. This project and others like it have laid the technical foundation on which a successful ethanol engine industry could be built.

However, very few new truck projects are being launched using ethanol. The barrier to wider ethanol use is more economic than technical. Because the trucking industry operates with a tight profit margin of about 2%, its fuel choice will depend heavily on fuel costs. As Bill Peerenboom, vice president of the American Trucking Association's Foundation pointed out at a recent international alternative fuels conference, "The only way a fuel will compete on a long-term basis is on its economics."

Several active research projects, at NREL and elsewhere, are working toward low-cost ethanol production from a variety of feedstocks. When the cost differential between ethanol and diesel fuel becomes more favorable for ethanol, we will see more ethanol trucks on the nation's highways.

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Where Can I Get One of Those!

For the past several years, there has been little market demand for the ethanol 6V92 engine and DDC discontinued offering them. Recently, however, interest has been renewed. Los Angeles Mass Transit has placed an order for new ethanol 6V92 engines and DDC plans to recertify the engine to 1996 emissions standards. For more information about the availability of the engine, contact Patrick Scully at DDC: (313) 592-5292.

Further Information

The Ethanol Heavy-Duty Truck Fleet Demonstration Project - Final Report
Norman J. Marek
http://www.afdc.doe.gov/demoproj/hdv/hdvsect.html

Alternative Fuel Transit Buses, Final Results from the National Renewable Energy Laboratory Vehicle Evaluation Program
Robert Motta, et al.
http://www.afdc.doe.gov/demoproj/bus/busdoc.html

Biofuels Update
Quarterly Newsletter
http://www.afdc.doe.gov/bionews

For these reports or further information about alternative fuels, visit our World Wide Web site at ***http://www.afdc.doe.gov*** or call the Alternative Fuels Hotline at ***(800) 423-1DOE.***

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