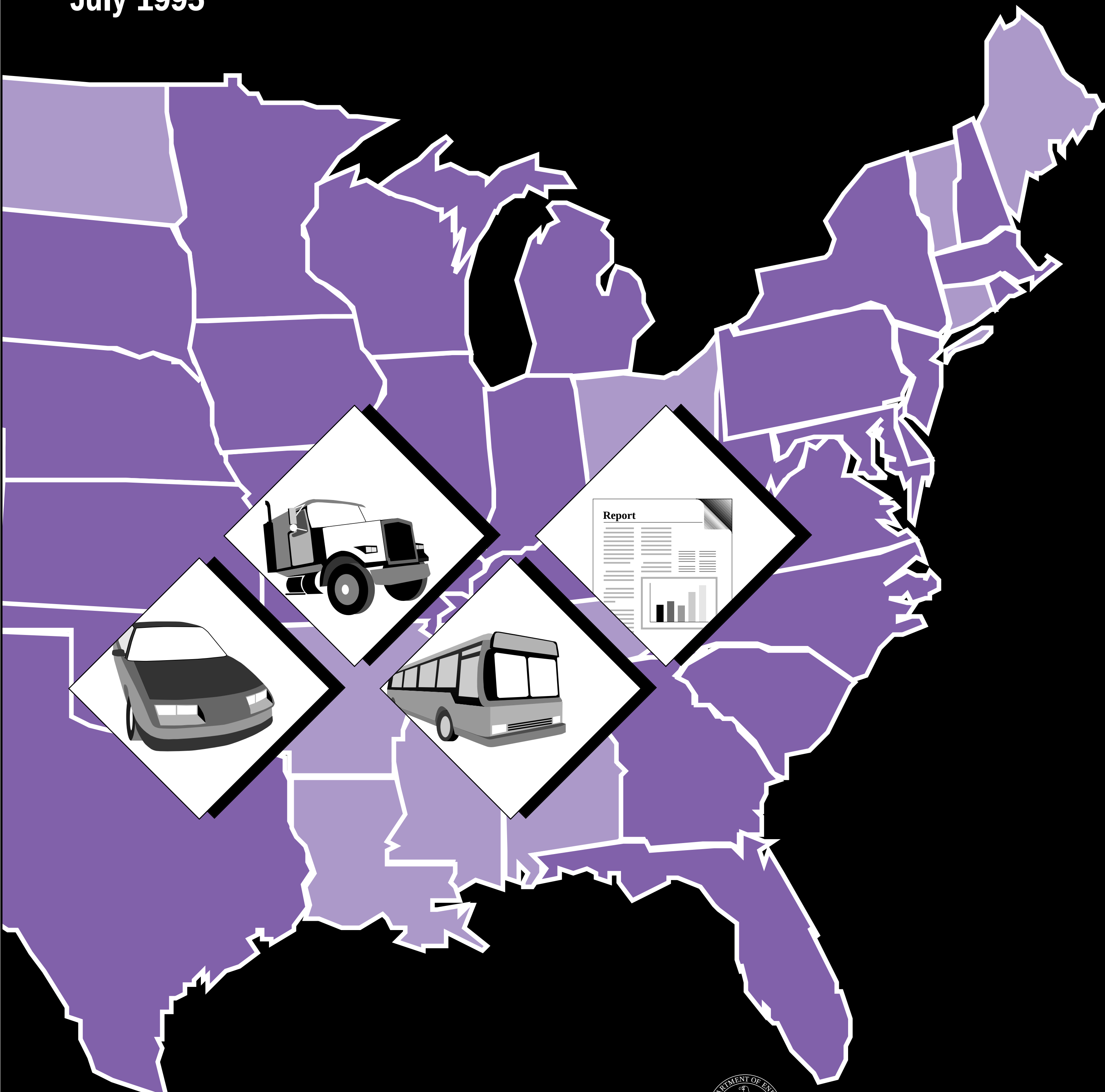
Federal Alternative Motor Fuels Programs

Fourth Annual Report to Congress

July 1995



U.S. Department of Energy
Office of Transportation Technologies
Office of Energy Efficiency and Renewable Energy

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Acknowledgments

The U.S. Department of Energy gratefully acknowledges the cooperation of the participating Government agencies in the Alternative Motor Fuels Programs—the General Services Administration, the National Highway Traffic Safety Administration, the Environmental Protection Agency, and the many other Federal agencies that are operating these vehicles and supplying valuable information on their operation. The Department also acknowledges the participation and cooperation of the vehicle and engine manufacturers, fuel suppliers, private fleet operators, and state and local transit companies. All involved have worked to make this program a success.

". . . the displacement of energy derived from imported oil with alternative fuels will help to achieve energy security and improve air quality."

—Alternative Motor Fuels Act of 1988

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Executive Summary

Abstract

This annual report to Congress presents the current status of the alternative fuel vehicle programs being conducted across the country in accordance with the Alternative Motor Fuels Act of 1988. These programs, which represent the most comprehensive data collection effort ever undertaken on alternative fuels, are beginning their fifth year. This report summarizes tests and results from the fourth year.

Summary of Results

Light-Duty Vehicles

The test program for light-duty vehicles analyzes the emissions, performance and reliability, fuel economy, and cost of passenger cars, minivans, and light vans and trucks that run on alternative fuels, and compares the results to similar control vehicles that run on gasoline. The alternative fuel vehicles being tested run on either alcohol fuels (ethanol or methanol) or on compressed natural gas (see sidebar, page 5). The alcohol vehicles are actually flexible-fuel vehicles—they are designed to run on various mixtures of alcohol and gasoline or on gasoline alone. In contrast, the compressed natural gas vehicles tested this year are designed to run only on their designated fuel.

In 1994, the program collected data on 603 vehicles that operate on alternative fuels and 243 control vehicles that operate on gasoline only. The models being tested include Chevrolet Luminas, Dodge Spirits, Ford Tauruses, Chevrolet C-2500 pickups, Dodge B-250 vans, and Ford Econoline vans. Of the alternative fuel vehicles, 45 are designed to run on E85 (a mixture of 85 percent ethanol and 15 percent gasoline), 338 are designed to run on M85 (a mixture of 85 percent methanol and 15 percent gasoline), and 220 are designed to run on compressed natural gas.

Emissions

Using standard testing procedures, the program tests and compares the emissions of vehicles running on alternative fuels to those of vehicles operating on reformulated gasoline. The emissions results are also compared to the 1996 Federal emissions standards (known as Tier 1), which mandate the maximum allowable emissions for regulated pollutants on a basis of grams per mile. The regulated pollutants are hydrocarbons, non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen.

Of the 279 vehicles to be tested in Phase II, the program has tested 146 vehicles to date. The results of the measurements made to date are summarized in Figure 1. With the exception of Ford Econoline vans running on 85 percent methanol, the emissions for every kind of alternative

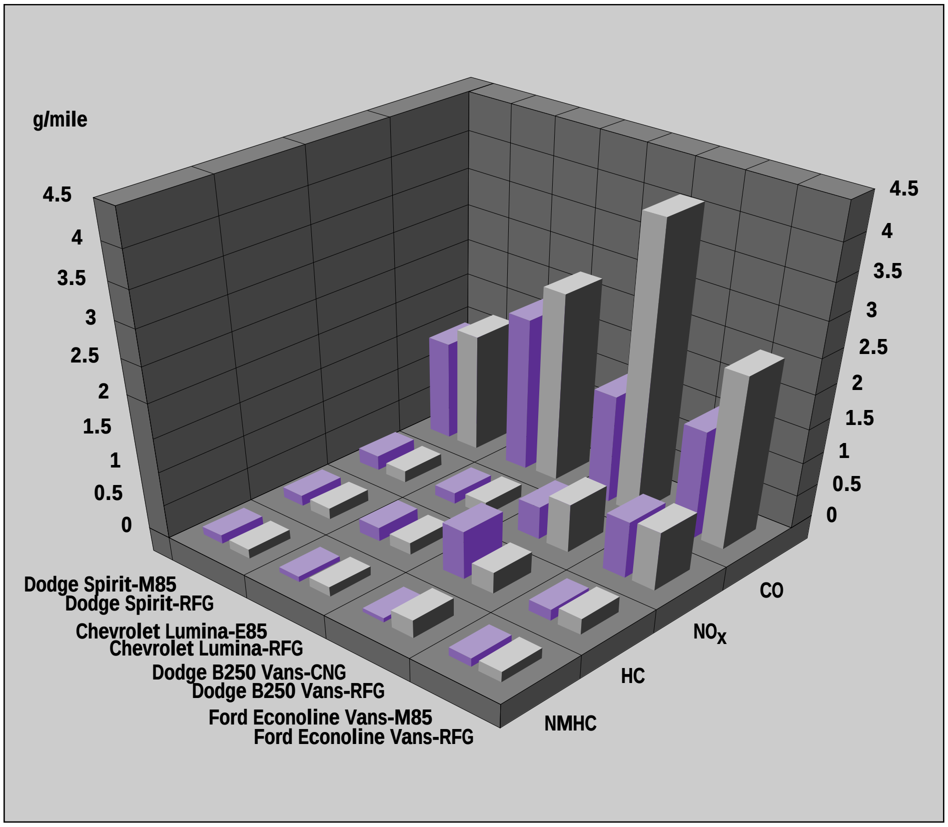


Figure 1. Emissions results for light-duty vehicles

fuel vehicle tested were below the Tier 1 standards for every pollutant. The emissions from the Ford Econoline vans running on 85 percent methanol exceeded the standard for oxides of nitrogen by only a small amount.

The results also show that, in general, the emissions from the alternative fuel vehicles were less than those from the control vehicles operating on reformulated gasoline. The nonmethane hydrocarbon emissions from vehicles running on natural gas were considerably lower. However, total hydrocarbon emissions from these vehicles were significantly higher. Methane, which makes up the difference, does not contribute significantly to the formation of photochemical smog, but is a highly active greenhouse gas. In addition, oxides of nitrogen emissions from vehicles operating on 85 percent methanol were slightly higher.

Performance and Reliability

As expected, because the vehicles operating on alternative fuels are in an early phase of development, they have suffered more reliability problems than have gasoline vehicles, which have a long development history. Also as expected, as the testing program has progressed and as the manufacturers have changed their vehicle designs based on earlier experience, the new models of alternative fuel vehicles are achieving a higher level of reliability than earlier ones.

Fuel Economy

The program measures the fuel economy of light-duty vehicles in two ways: by testing the vehicles in a laboratory with a chassis dynamometer and by analyzing refueling records. All figures are reported as miles per gasoline equivalent gallon, which is actually a measure of the energy efficiency of the vehicle per a common energy unit. The dynamometer tests are averaged for each type of vehicle/fuel combination and reported as a single point. The refueling records indicated a wide range of miles per unit energy for each type of vehicle/fuel combination; this is understandable because the records indicate "real world" driving cycles in which the conditions vary considerably.

The results of both types of tests indicate that, for all of the models, the fuel efficiencies of alternative fuel vehicles are very close to those of gasoline vehicles. For example, in the dynamometer tests, the average fuel economy for Dodge Spirits running on methanol was about 24 miles per gasoline equivalent gallon, the same as the average for Dodge Spirits operating on gasoline. In fact, the greatest difference in the dynamometer testing occurred between pickup trucks running on compressed natural gas, which averaged 12 miles per gasoline equivalent gallon, and those running on gasoline, which averaged 14 miles per equivalent gallon.

The greatest disparity for the "real world" analyses occurred between Chevrolet Luminas running on methanol, which ranged between 10 and 29 miles per equivalent gallon, and Luminas running on gasoline, which ranged between 20 and 28 miles per equivalent gallon. But this disparity is probably due to different driving cycles and driving styles.

Cost

Generally, at this point, the total cost of owning and operating an alternative fuel vehicle is slightly higher than that of owning and operating a vehicle that runs on gasoline. Total vehicle cost includes costs for acquisition, maintenance, insurance, fuel, and oil.

For alcohol vehicles, fuel costs are higher than those for gasoline vehicles, but the incremental cost of acquisition is relatively low. For vehicles that run on compressed natural gas, on the other hand, fuel costs are lower than gasoline while incremental vehicle acquisition costs are significantly higher.

Transit Buses

The test program for transit buses analyzes the emission levels, fuel economy, reliability, and operating cost of a sample of transit buses currently operating on alternative fuels. Currently, the program is testing 98 buses in 7 metropolitan areas. Forty of these buses run on diesel fuel using standard diesel engines from Detroit Diesel Corporation and Cummins Engine Company. Five use standard diesel engines, but operate on B20, a blend of 20 percent biodiesel and 80 percent conventional diesel fuel. B20 is not considered an alternative fuel under the Energy Policy Act of 1992.

Twelve of the buses use diesel engines with a particulate trap. And 40 use engines modified to run on alternative fuels: liquefied natural gas (dual-fuel engines that also operate on diesel), compressed natural gas, 100 percent methanol, and 95 percent ethanol.

Emissions

Two types of tests are used to measure emissions. The first is an engine dynamometer that tests only the engine, to certify it for operating on specific fuels. The second is a chassis dynamometer in which the entire bus is tested in a laboratory according to a standard Central Business District driving cycle. The buses are tested for the same pollutants as are the light-duty vehicles, as well as for emissions of particulate matter, and are compared to heavy-duty standards.

At this time the program has used the engine dynamometer to certify two versions of the Detroit Diesel 6V92TA engine: the standard engine for operating on diesel and an engine modified to run on methanol. Certification data for the methanol engine indicate that its emissions are well below the standards set by the Environmental Protection Agency and that they are also generally well below the emissions from the standard Detroit Diesel 6V92TA diesel engine.

The initial results of the chassis dynamometer tests for buses using Detroit Diesel engines are quite variable and inconclusive. Nonetheless, we can observe that buses using alcohol generally emit fewer oxides of nitrogen and less particulate matter, but more hydrocarbons and carbon monoxide than do buses using diesel.

Similarly, although buses running on engines from Cummins Engine Company may still be considered to be demonstration units, we can make the general observation that those using compressed natural gas emit less particulate matter and more hydrocarbons than those using diesel. The additional hydrocarbon emissions from the natural gas vehicles are probably mostly methane, which is not reactive. Plans are to include the measure of methane in future emissions testing.

Fuel Economy

The fuel economy of buses, expressed in miles per diesel equivalent gallon, was measured in a fashion similar to that of light-duty vehicles—with a chassis dynamometer (using a Central Business District driving cycle) and by analyzing refueling records.

The results from the chassis dynamometer tests indicate that there is very little difference between the average fuel efficiency of buses using alternative fuels and those using diesel. The greatest difference occurred in Tacoma, Washington, where buses running on compressed natural gas averaged a little more than 3 miles per equivalent gallon, whereas those using diesel averaged a little less than 4 miles per equivalent gallon.

The results from the refueling records suggest that the fuel economies varied from site to site, that those sites with narrow ranges in fuel economy for diesel engines tended to have tight ranges for alternative fuel engines, and that fuel economies of alternative fuel engines were similar to those of diesel engines for a given site.

Reliability

Using road calls per 1,000 miles as a measure of reliability, no general trend has emerged. We can note, however, that the dual-fuel buses in Houston that run on liquefied natural gas and diesel required far more road calls than the control buses running on diesel. Much of this can be attributed to the buses running out of fuel. If a fuel problem develops with the liquefied natural gas, the dual-fuel engines are designed to run on diesel as a backup. In this case, the bus runs out of fuel in a short time because of the small size of the diesel tank. We also note that the ethanol buses in Peoria report slightly fewer road calls than their diesel counterparts. For the buses tested in the three other cities we can make no confident conclusion because of the small number of miles traveled by the alternative fuel buses.

Cost

With the exception of the Tacoma buses operating on compressed natural gas, alternative fuel buses tend to have higher total acquisition and operations costs than their diesel counterparts, often appreciably higher. This can be attributed to higher acquisition prices (because of the modified, developmental engines and fuel tanks), and to higher maintenance costs (for some of the engine types). As more alternative fuel engines are built and sold, and as more experience is gained, maintenance costs and incremental engine costs should decrease.

In Tacoma, on the other hand, compressed natural gas is relatively inexpensive and the maintenance cost for buses that use the compressed natural gas is comparable to that of the diesel controls.

Medium- and Heavy-Duty Vehicles

The heavy-duty vehicle program collects and analyzes data on the emissions, fuel economy, and cost of two types of vehicles: medium-duty commercial delivery vans and large trucks. For large trucks, the program also analyzes performance and reliability.

The program currently tracks 134 Chevrolet, Dodge, and Ford delivery vans from two commercial fleets: the

The Alternative Fuels Being Tested

In all, the three programs being managed by the Department of Energy are testing six kinds of alternative fuels: methanol, ethanol, biodiesel, compressed natural gas, liquefied natural gas, and propane. What are these alternative fuels and why are we testing them?

Methanol. Methanol is an alcohol derived primarily from natural gas, but it can also be derived from biomass or coal. Thus the potential domestic resource base for methanol is vast. Methanol's combustion holds the promise of producing less carbon monoxide and non-methane hydrocarbons than gasoline and less particulate matter than diesel. It may also be converted into methyl tertiary butyl ether and then used as a high-octane, oxygenated additive with gasoline.

Ethanol. Ethanol is an alcohol derived from biomass (corn, sugar cane, grasses, trees, and agricultural waste). The potential domestic resource base for ethanol is also vast. Ethanol's combustion promises emissions similar to those from methanol. And, like methanol, it also can be used to make a high-octane, oxygenated ether.

Biodiesel. As tested in this program, biodiesel is actually 80 percent conventional diesel and 20 percent diesel derived from biomass, microalgae, or agricultural waste. Although it has properties similar to conventional diesel fuels, its potential value derives from the fact that its production can be based on a domestic and renewable resource base.

Compressed Natural Gas and Liquefied Natural Gas. Natural gas is primarily methane (approximately 93 percent) with a mixture of other gaseous hydrocarbons. It is derived from gas wells or in conjunction with crude oil production. The United States has proven natural gas reserves of approximately 170 trillion cubic feet; current natural gas consumption is primarily (89 percent) derived from domestic sources, with the remainder coming mainly from Canada. Relative to gasoline, the combustion of natural gas promises to cut emissions of carbon monoxide and non-methane hydrocarbons. The difference between the compressed and liquefied versions of natural gas lies in the phase in which they are stored. To obtain the liquefied version, the gas must be cooled considerably and stored in insulated tanks.

Propane. This is a gas composed primarily of propane and other gaseous hydrocarbons. It is extracted from natural gas or refinery gas streams. Its emissions are expected to be similar to those of natural gas.

Federal Express CleanFleet and the United Parcel Service Fleet. Twenty of these vans run on 85 percent methanol, 20 on propane, 41 on compressed natural gas, 21 on reformulated gasoline, and 32 (the control group) on standard unleaded gasoline.

The program is also tracking 21 large trucks. Seven of these operate on compressed natural gas, 8 on 95 percent ethanol, and 6 (the control group) on standard diesel. Also, 7 of the trucks are used for line haul, 5 for road maintenance, and 9 for hauling garbage.

Emissions

Using chassis dynamometers and the Federal Test Procedure, the program is testing 36 of the Federal Express CleanFleet vans for emissions of hydrocarbons, non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen.

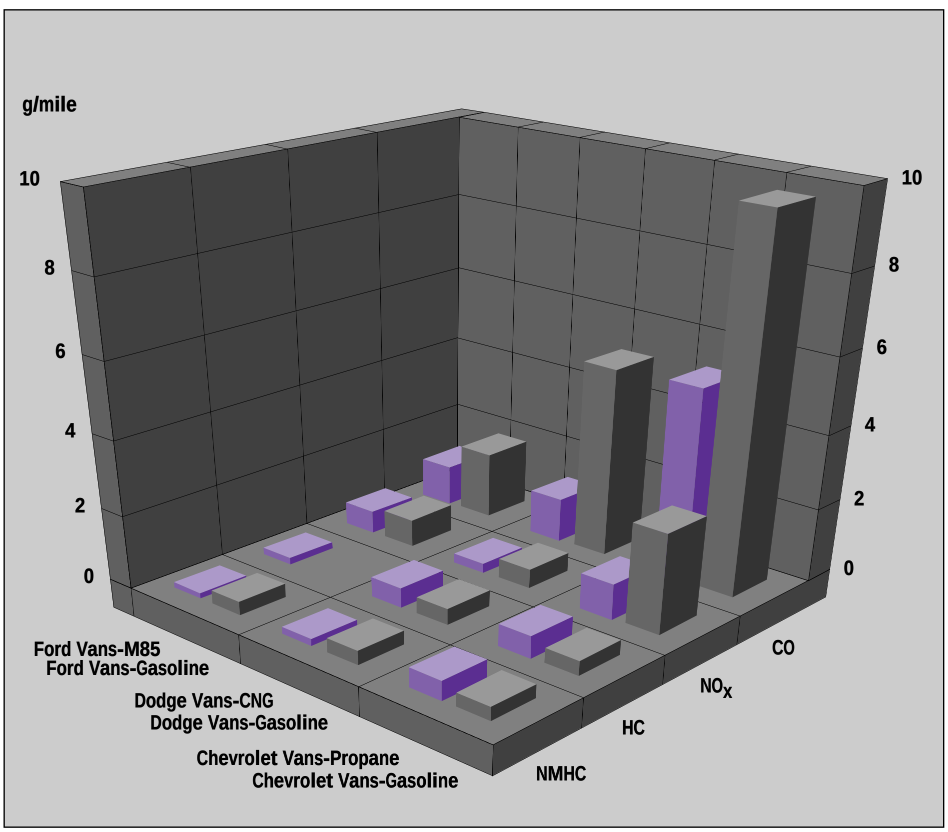
With some variance, the vehicles operating on alternative fuels generally emitted less carbon monoxide, fewer non-methane hydrocarbons, and more total hydrocarbons than vehicles running on standard unleaded gasoline (Figure 2). In addition, with few exceptions, the Dodge and Ford vans operating on alternative fuels met the Tier 1 emission standards for all pollutants. Chevrolet alternative fuel vans, however, did not consistently meet the standards for all regulated emissions.

During 1994, the program also devised a new driving cycle with which to use a chassis dynamometer to test the emissions of large trucks. It is currently using the new cycle to test the emissions from some of the line-haul trucks in the program. The results to date are preliminary, and it is not yet known whether this new cycle will become the emissions testing standard for large trucks.

Performance and Reliability

The program collects data on maintenance and repair records of the large trucks and tests their performance on characteristics such as acceleration, hill climbing, driveability, and driver acceptance. This part of the testing program is in its preliminary stages, and the data recorded thus far are serving primarily to identify issues and to help manufacturers make design improvements in their engines.

Figure 2. Emissions results from the CleanFleet



Fuel Economy

The program measures the fuel economy of trucks in two ways: by analyzing refueling records and by performing chassis dynamometer measurements. The fuel economy is measured in terms of miles per gasoline equivalent gallon for delivery vans and miles per diesel equivalent gallon for large trucks.

For the large trucks, most of the fuel economies for the alternative fuel vehicles were comparable to those of their diesel counterparts. However, the fuel economy of a line-haul truck using a Caterpillar 3406 engine modified for compressed natural gas was considerably lower than its diesel counterpart. The engine has recently been retrofitted to address the discrepancy.

For the delivery vans, Dodges and Chevrolets operating on compressed natural gas and on propane tended to have fuel economies that were 10 percent to 15 percent lower than their unleaded gasoline counterparts. All alternative fuel Ford delivery vans, however, had fuel economies comparable to their gasoline counterparts.

Cost

As with the buses and light-duty vehicles, the cost to acquire, operate, and maintain alternative fuel heavy-duty vehicles tends to be greater than that to operate and maintain vehicles using conventional fuel. This is largely because of the additional vehicle acquisition cost and the cost of fuel.

Summary

In summary, these programs have made significant progress in comparing alternative fuel vehicle performance with that of their conventional counterparts. The data gathered to date clearly show the promise that alternative fuel vehicles offer the nation’s future in terms of economic stability, energy independence, and improved air quality. Widespread acceptance and use of these vehicles will reduce our dependence on imported petroleum, enhance our national security, improve environmental quality, and potentially create thousands of jobs through the displacement of imported petroleum with domestically produced alternative fuel. However, much work remains to be done before this promise becomes reality. We have many more miles to go in these programs to increase the confidence level of the findings and to fully evaluate the true potential of these vehicles.

Background

Establishing the Programs

In 1988, Congress passed the Alternative Motor Fuels Act, Public Law 100-94. Recognizing that the displacement of energy derived from imported oil with alternative fuels will help achieve energy security and improve air quality, the lawmakers designed this legislation to encourage the development of vehicles that could run on alternative fuels, such as methanol, ethanol, and natural gas.

Public Law 100-94 amended Title III of the Energy Policy and Conservation Act (the Act) by adding a part (Part J) that directed the Department of Energy to cooperate with other agencies to acquire and operate vehicles that use alternative fuel (42 U.S.C. 6374, et seq.). The amendment also required the Department of Energy to conduct a study of the performance, fuel economy, emissions, and costs of these vehicles in comparison with those that run on conventional fuels, and to provide to Congress an annual report of that study (see sidebar, page 11). This is the fourth annual report on the study program set up by the Department of Energy.

The Programs

In 1990, under the provisions of the Act, the Department of Energy cooperated with other Federal agencies to establish three programs of study:

- The Alternative Fuel Light-Duty Program. In this program, established under section 400AA of the Act (42 U.S.C. 6374), the General Services Administration annually purchases a practicable number of passenger cars and light-duty trucks and vans for use in the fleets of various agencies of the Federal Government. The Department of Energy cooperates with vehicle manufacturers, vehicle dealerships, government agencies, test laboratories, and others to collect and analyze data on a selected subset of these vehicles and compares these data with data collected from vehicles operating on gasoline. The vehicles are operated at various locations across the nation (Figure 3) to capture the effects of climatic conditions and altitude on vehicle operation and maintenance.

  This program studies vehicles that operate on methanol, ethanol, compressed natural gas, and gasoline. Those operating on methanol or ethanol are actually flexible-fuel vehicles, which means that they can operate on their designated alcohol, on gasoline, or on any mixture of the alcohol (up to 85 percent) and gasoline. Those operating on compressed natural gas or gasoline are dedicated vehicles, which means they operate only on the fuel for which they are designated. Those dedicated

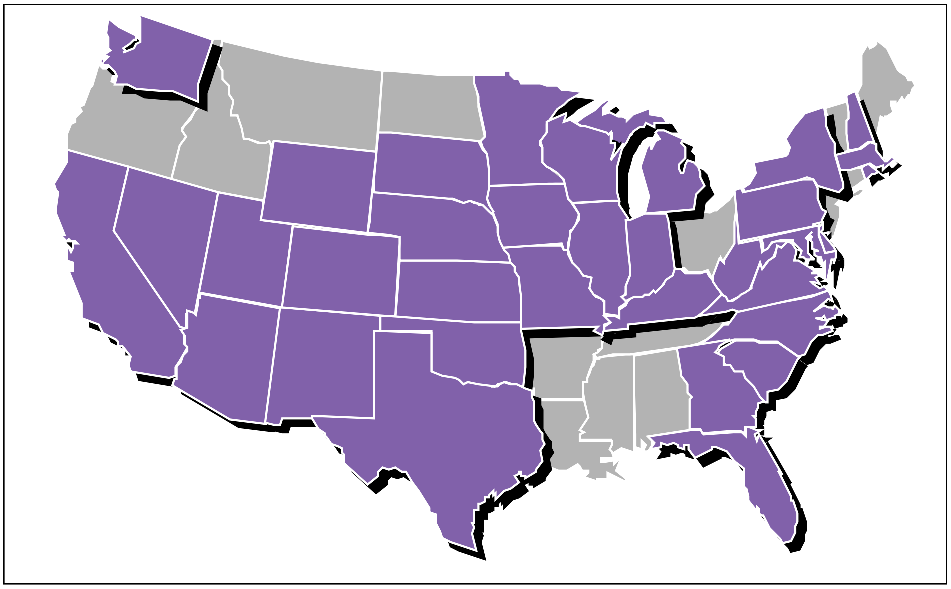


Figure 3. Under the programs established by the Act, alternative fuel vehicles are being tested at a variety of locations across the United States.

vehicles operating on gasoline are control vehicles that serve as a baseline for comparison.

- The Alternative Fuels Transit Bus Testing Program. In this program, established under section 400CC of the Act (42 U.S.C. 6374b), the Department of Energy cooperates with test laboratories, engine and chassis manufacturers, government agencies, transit authorities, and others to test the operation and maintenance of alternative fuel buses in seven municipalities across the nation.

  The program tests vehicles with engines and fuel systems modified to run on methanol, ethanol, liquefied and compressed natural gas, and biodiesel. The buses running on conventional diesel fuels are used as a basis for comparison. The buses in the program running on liquefied natural gas also require diesel fuel as a pilot ignition source. All the other types of alternative fuel buses in the program are dedicated to run on the fuel for which they are modified.

  The bus test program should prove quite valuable for transit authorities. This is because, according to a survey conducted by the American Public Transit Association, the bus sector of the market is well ahead of other sectors in the market penetration of alternative fuel vehicles. Approximately 50,000 transit buses in the United States run on alternative fuels; this represents about 5 percent of the bus market. But until the inception of this program, no systematic data were collected on the operation and maintenance of these vehicles. Also, a transit bus is an ideal application of alternative fuels because the buses are centrally refueled (requiring less infrastructure development), and because extra space is generally available on a bus to store the sometimes bulky fuel tanks. This makes it possible that the market for alternative fuel vehicles could grow faster for buses than for smaller vehicles, a possibility that makes good data all the more crucial.

- The Alternative Fuels Truck Commercial Application Program. Also known as the alternative fuels heavy-duty vehicle program, this program was established under section 400BB of the Act (42 U.S.C. 6374a). Under this program, the Department of Energy is cooperating with municipalities, state and local governments, other Federal agencies, and private fleet operators to test the real-life operation and maintenance of two types of vehicles running on alternative fuels: commercial delivery vans and heavy trucks.

The program tests trucks and vans running on methanol, ethanol, compressed natural gas, and propane. (In general, the vehicles are dedicated to running on a specific type of fuel.) It compares the data from these vehicles with data from control vehicles operating on unleaded or reformulated gasoline for the delivery vans and diesel fuel for the heavy trucks.

Because large trucks are typically very expensive, the program shares the cost of the test vehicles with private fleet owners or state or local governments. The program's heavy test trucks are modified to run on methanol, ethanol, compressed natural gas, or biodiesel. The goal of this part of the program is to test as many of the currently available alternative fuel engines as possible and to compare the cost and performance of these engines with that of standard diesel engines.

For commercial vans, the program is tracking two delivery fleets: the Federal Express CleanFleet, and the United Parcel Service Fleet. The Federal Express CleanFleet includes vehicles operating on compressed natural gas, propane, and 85 percent methanol. The only alternative fuel used by vehicles in the United Parcel Service fleet is compressed natural gas. The program collects data from these vehicles and compares the information to that collected from vehicles using similar engines but operating on unleaded gasoline or reformulated gasoline.

The Program Partnership

Although the Act assigns to the Department of Energy the responsibility for testing the vehicles and reporting the results to Congress, these programs are truly a partnership among a variety of parties ranging from automobile manufacturers to Federal agencies to national laboratories to cities to private fleet operators. Each has an important role to play and a vested interest in seeing the job come to a successful conclusion:

- The Department of Energy manages the programs and cooperates with other Federal agencies, state and local governments, and private companies to ensure the smooth operation of the programs.
- The National Renewable Energy Laboratory is the field manager for the testing programs. The laboratory coordinates the testing efforts, collects all the data at its Alternative Fuels Data Center, analyzes and summarizes the data, and makes the information available to all interested and qualified parties.
- The General Services Administration purchases many of the vehicles to be used in the programs and then distributes them to the various Federal agencies, who use them in their fleets and participate in the testing programs.
- The Environmental Protection Agency sets regulations for emissions and defines standard methods for measuring those emissions.

The Alternative Motor Fuels Act of 1988

Congress passed the Alternative Motor Fuels Act to encourage—

(1) the development and widespread use of methanol, ethanol, and natural gas as transportation fuels by consumers; and

(2) the production of methanol, ethanol, and natural gas powered motor vehicles.

The Act directs the Secretary of Energy to cooperate with the Environmental Protection Agency and the National Highway Traffic Safety Administration to conduct a study of alternative-fueled vehicles, which shall address—

(i) the performance of such vehicles, including performance in cold weather and at high altitude;

(ii) the fuel economy, safety, and emissions of such vehicles; and

(iii) a comparison of the operation and maintenance costs of such vehicles to the operation and maintenance costs of other passenger automobiles and light-duty trucks.

The Act also directs the Secretary of Energy to provide a report on this study to the Committees on Commerce, Science, and Transportation and Governmental Affairs of the Senate, and to the Committee on Commerce of the House of Representatives, within one year after the first such vehicles are acquired, and annually thereafter.

- Original equipment manufacturers—such as General Motors, Chrysler, Ford, Detroit Diesel Corporation, and Cummins—design and modify engines and vehicles to operate on alternative fuels. They also help to test the engines and vehicles and collect data, which they send to the Alternative Fuels Data Center.

- Automobile dealers keep records on the maintenance and repairs they perform on light-duty vehicles in the test program. These records are forwarded to the Alternative Fuels Data Center for compilation; they are also used by the program and by the vehicle manufacturers to help determine the redesigns that may be necessary to overcome recurrent problems with vehicle types.

- Several municipal transit agencies take part in the transit bus program, maintaining, refueling, and repairing buses that run on alternative fuels. They then forward their records on bus operation and maintenance to the Alternative Fuels Data Center. The transit agencies also cooperate with test laboratories that visit their facilities to measure the emissions and fuel economy of the buses.

- Some municipalities cooperate in the program for testing heavy-duty vehicles by, for example, operating and maintaining garbage trucks that run on alternative fuels. They forward all records to the Alternative Fuels Data Center for compilation. Many municipalities are interested in exploring options to relieve pollution and thus help prove and test the vehicles.

- A variety of Federal agencies also cooperate with the Department of Energy and the General Services Administration by planning the purchase of alternative fuel vehicles for their fleets and then using some of these vehicles in the test programs.

- The program for heavy-duty vehicles collects data from two companies that use alternative fuel delivery vans in their commercial fleets.

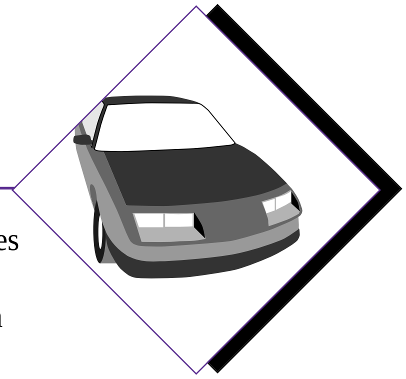
- Private test laboratories in several states have contracted with the Department of Energy to test the emissions and fuel economy of vehicles being used in the program. They use dynamometers to perform standardized tests; collect, analyze, and reduce the data; and send the data to the Alternative Fuels Data Center for compilation and further analysis and reduction.

- West Virginia University travels to the various municipalities, taking part in the programs for heavy-duty vehicles and transit buses. The university uses its transportable chassis dynamometer to measure the emissions and fuel economy of the trucks and buses.

- The University of Missouri gathers data on the operation and maintenance of the buses in St. Louis running on biodiesel and transfers the data to the Alternative Fuels Data Center.

- Drivers of many of the test vehicles also gather data on refueling, mileage in real-world situations, and problems encountered.

Light-Duty Vehicles



Overview

The test program for light-duty vehicles was designed to respond to the requirements of section 400AA of the Energy Policy and Conservation Act to study emissions, maintenance, safety, and fuel economy on passenger cars, minivans, and light vans and trucks that operate on alternative fuels. The Alternative Motor Fuels Act directs the General Services Administration to purchase these vehicles from manufacturers that make the original vehicles. The General Services Administration is the Federal agency primarily responsible for purchasing alternative fuel vehicles for use in the Federal fleet.

Alternative fuel vehicles built by the manufacturers are either “flexible-fuel” or “dedicated.” Flexible-fuel vehicles can run on more than one fuel type or a mixture of fuel types. All alcohol vehicles currently in the program are flexible-fuel vehicles—they are able to run on gasoline alone or on various mixtures of gasoline and the alcohol fuel for which they are modified (ethanol or methanol). Relatively minor design modifications are needed to turn a gasoline vehicle into a flexible-fuel alcohol vehicle. Changes include using alcohol-resistant materials in the fuel system, adding a fuel sensor, and replacing the engine microprocessor with one designed specifically for flexible-fuel control.

The compressed natural gas vehicles in the program are dedicated vehicles—they can operate only on compressed natural gas. Because a gaseous fuel is used, these vehicles require more modifications than the flexible-fuel alcohol vehicles. The fuel tank is replaced by high-pressure gas cylinders, which require a fuel pressure regulator. Other changes include adding a fuel temperature sensor, a pressure relief device, and a new fuel induction system.

The models available from the manufacturers change each year, and the General Services Administration purchases replacement vehicles yearly. The agency strives to purchase as many alternative fuel vehicles as budget and availability will allow. The General Services Administration leases the vehicles to Federal agencies and their contractors, who operate the vehicles in standard Federal work duty. Table A-1 in the Appendix lists the 42 Federal agencies participating in the program.

Refueling a flexible-fuel 85 percent methanol Chevrolet Lumina

The Act requires data collection on a representative subset of the alternative fuel vehicles in the Federal fleet. Of several thousand vehicles in the Federal fleet, the program is collecting data on 603 vehicles that operate on alternative fuels and on 243 that operate on gasoline only, which serve as a control group (see Figure 4). Also, because emissions, maintenance, safety, and fuel economy can be affected by climatic conditions and altitude, the program collects data on different types of vehicles at various locations around the country (see Figure 5).

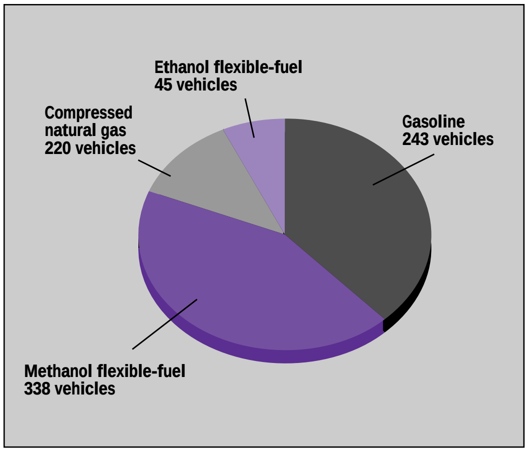


Figure 4. Vehicles in the 1994 test fleet

Each year, the program adds vehicles to its data collection effort only if the vehicles differ in design from those already in the program. This year the program added 1994 Dodge minivans (dedicated compressed natural gas), 1994 Dodge B-250 vans (dedicated compressed natural gas), and 1994 Ford Tauruses (flexible 85 percent ethanol).

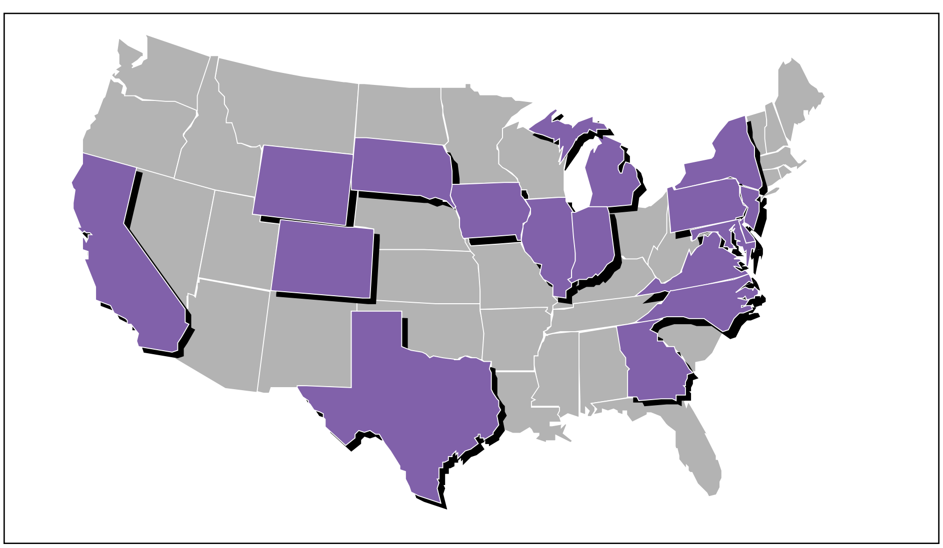
The General Services Administration usually requires passenger cars to be removed from service after 3 years and vans and trucks to be removed after 7 years. Accordingly, this year the program removed from service its 1991 Ford Tauruses and its 1991 Chevrolet Luminas (both are flexible 85 percent methanol). The 39 Ford Tauruses were converted to dedicated gasoline vehicles and sold at a General Services Administration auction. Five of the Chevrolet Luminas were moved to the National Renewable Energy Laboratory for additional testing. The other 20 Luminas were sold at a General Services Administration auction.

The program also removed its 1992 Chevrolet C-2500 pickups from service (dedicated compressed natural gas). Although these pickup trucks were not scheduled to be removed from service for several years, General Motors recalled them through a repurchase program after two vehicles (outside the Federal fleet) experienced fuel-tank failures.

Since the program's inception in 1991, experience with alternative fuel vehicles has grown steadily. This can be seen in the cumulative miles traveled by vehicles in the program (see Figure 6). Table A-2 in the appendix summarizes the status of the current test fleet.

To fulfill the requirements of the Act, the program collects data from drivers, maintenance facilities, the General Services Administration, and emissions laboratories. Drivers report mileage, fuel usage, and performance problems. The program collects maintenance data from General Services Administration records, which it supplements with repair invoices from the service

Figure 5. Locations of light-duty test vehicles



departments of vehicle dealerships. Periodically, the program removes a subset of the vehicles for emissions testing; this testing is performed by laboratories approved by the Environmental Protection Agency.

The following sections analyze the emissions, performance and reliability, cost, and fuel economy of light-duty vehicles in the test program.

Emissions

Emissions measurement is the single most comprehensive part of the test program for light-duty vehicles. The effort extended here is also the most extensive and carefully controlled study of emissions of alternative fuel vehicles in the world. The data collection activities, which are essential to fully ascertain the long-term emissions of light-duty vehicles operating on alternative fuels, may be divided into two parts: Phase I and Phase II.

Phase I Emissions Testing

Phase I testing began in 1991 and lasted through 1994. The program tested 18 vehicles during this phase—7 flexible-fuel Luminas, 2 gasoline Luminas, 7 flexible-fuel Tauruses, and 2 gasoline Tauruses. Each vehicle was tested at odometer readings of 4,000 and 10,000 miles, and subsequently at 10,000-mile intervals. Nationally recognized facilities tested the vehicles using chassis dynamometers (see sidebar, page 18) to measure emissions according to the Federal Test Procedure - *Code of Federal Regulations, Title 40, Part 86, Emissions Certification and Test Procedures.*

The program stopped testing these vehicles when the General Services Administration removed the vehicles from its fleet. The National Renewable Energy Laboratory, however, obtained several of the original vehicles to continue the emissions tests at higher mileage levels.

Last year, the *Third Annual Report to Congress* presented the detailed emissions results from Phase I. Because of the small number of vehicles tested, the availability of only 85 percent methanol vehicles, and the variability of results in Phase I, the conclusions presented were limited. Phase II was designed to address the problems encountered in Phase I.

Phase II Emissions Testing

To achieve a higher level of statistical certainty and to obtain results from a wider range of alternative

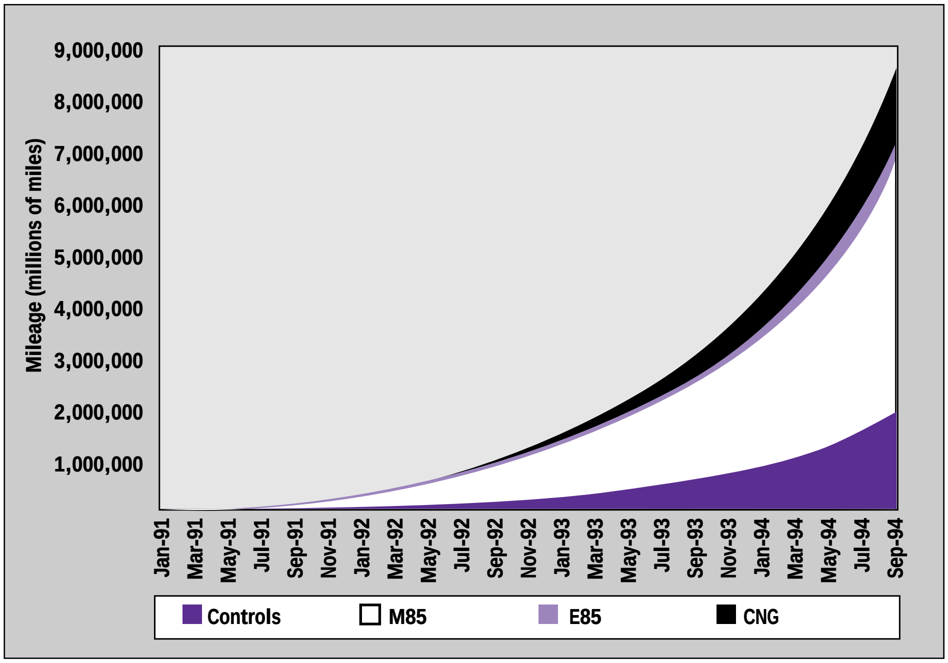


Figure 6. Light-duty vehicle mileage accumulation

Abbreviations

CNG = Compressed natural gas

CO = Carbon monoxide

HC = Hydrocarbons

LNG = Liquefied natural gas

NMHC = non-methane hydrocarbons

OMNMHCE = Organic material non-methane hydrocarbon equivalent

NO_X = Oxides of nitrogen

PM = Particulate matter

RFG = Reformulated gasoline

E50 = 50 percent ethanol

E85 = 85 percent methanol

E93 = 93 percent ethanol, 5 percent methanol, and 2 percent kerosene

E95 = 95 percent ethanol

M50 = 50 percent methanol

M85 = 85 percent methanol

M100 = 100 percent methanol

Emissions Testing Procedures

Before testing begins, the laboratory puts each vehicle through a detailed preconditioning procedure. This ensures that the vehicle is running only on the test fuel and that each car tested has the same recent driving history. The vehicle is then allowed to cool for 12 to 36 hours before testing. The Federal Test Procedure includes three tests: an evaporative emissions test while the vehicle is cold, a tailpipe emissions test while the vehicle is going through a driving cycle, then another evaporative emissions test after the vehicle has gone through the driving cycle and is at operating temperature.

For the evaporative emissions tests, operators put the vehicle in a sealed enclosure and measure the hydrocarbons that leak from the vehicle. Tailpipe emissions are measured while the vehicle is on a chassis dynamometer, a system that uses rollers to simulate driving conditions within a laboratory. This test lasts about 40 minutes. Beginning with a cold start, a driver closely follows a predetermined speed versus time curve while the dynamometer puts varying loads on the tires. This simulates the loads on a car during actual driving. After about 22 minutes, the driver turns the car off for 10 minutes, restarts it, and then follows another speed versus time curve while the dynamometer again varies the load on the tires. During the test, the system automatically measures emissions and fuel economy.

With a chassis dynamometer, the drive wheels of a test vehicle are supported by rollers that simulate driving conditions. Fuel economy and emissions are measured while driving on the dynamometer.

Immediately following this test, the laboratories subject the vehicles to an inspection and maintenance 240 procedure to test emissions. This is a chassis dynamometer test similar to the Federal Test Procedure, except that it lasts for only 4 minutes. Originally designed for private vehicles, this test is done with the vehicle at operating temperature because cars will be warmed up when they come in for emissions testing. To determine the value of the inspection and maintenance 240 test for low-emissions alternative fuel vehicles, the program is correlating its results with those of the 40-minute test.

fuels, the program initiated Phase II emissions testing in 1994. This phase calls for testing 279 vehicles; 146 of these are already being tested.

For this phase, the program used a competitive procurement to select the laboratories that were to perform emissions testing. The selection criteria included technical expertise (including experience in testing alternative fuel vehicles) and cost. The program selected Environmental Research & Development to test vehicles from the Washington, D.C., and New York regions; Automotive Testing Laboratories, Inc. to test vehicles from the Detroit and Chicago regions; and ManTech Environmental to test vehicles from the Denver region. The Denver test site will yield a high-altitude comparison on emissions performance.

The laboratories test the vehicles at the same odometer readings as in Phase I, using chassis dynamometers and the Federal Test Procedure. In addition, they are also using the Environmental Protection Agency's inspection and maintenance 240 test procedure (see sidebar, page 18). Phase II is also different from Phase I in that the program is now testing several types of vehicles: flexible-fuel vehicles running on 85 percent ethanol; flexible-fuel vehicles running on 85 percent methanol; dedicated vehicles running on compressed natural gas; and vehicles running on reformulated gasoline. The reformulated gasoline, California Phase II Certification Fuel (see sidebar on page 25) is used to make a comparison to alternative fuels.

To compare emission levels at different fuel-mixing ratios, the program tests the flexible-fuel vehicles on three fuels: a mixture containing 85 percent alcohol and 15 percent reformulated gasoline, a mixture containing 50 percent alcohol and 50 percent reformulated gasoline, and 100 percent reformulated gasoline. The kind of alcohol used in the mixtures depends on whether the vehicle is designed to run on ethanol or methanol.

For vehicles dedicated to operating on compressed natural gas, the program tests them on natural gas blended from tightly controlled constituent gases (93.05 percent methane, 3.41 percent ethane, 0.65 percent propane, etc.); this is designed to represent an industry-average fuel.

The program also compares the emissions of alternative fuels and those of reformulated gasoline to the Federal emissions standards, which mandate the maximum allowable emissions from vehicles on a grams per mile basis. The regulated emissions, called criteria pollutants, are hydrocarbons, carbon monoxide, and nitrogen oxides. Between 1994 and 1996, new standards are being phased in. The new standards regulate both total hydrocarbons and non-methane hydrocarbons for gasoline vehicles and organic material non-methane hydrocarbon equivalents (which include aldehydes and unburned alcohol) for alcohol vehicles. Methane is not included in the hydrocarbon regulations because it is non-reactive; therefore, it does not add to photochemical smog.

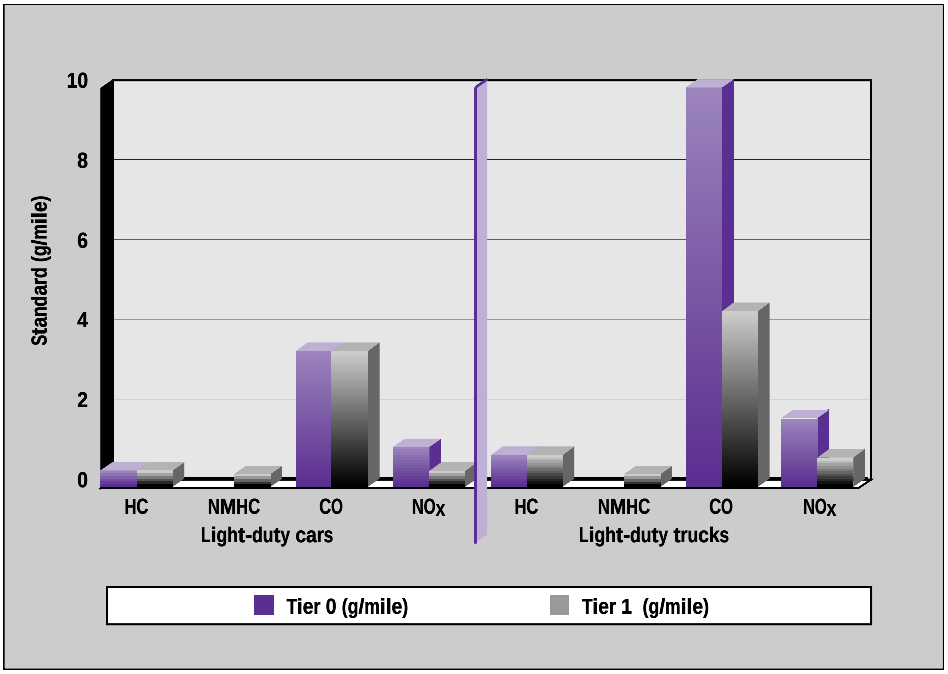
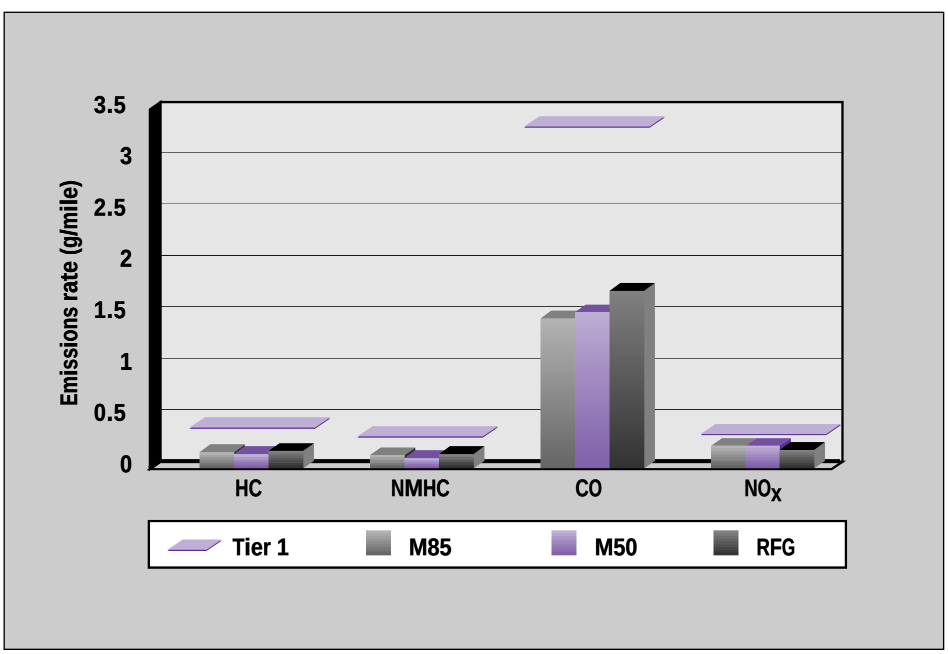


Figure 7. Tier 0 and Tier 1 emissions standards for light-duty cars and trucks. (Note that NMHC is not regulated in the Tier 0 standards.)

By 1996 the previous standards, known as Tier 0, will be completely replaced by the new standards, known as Tier 1. Figure 7 shows the Tier 0 and Tier 1 emissions standards for light-duty cars and trucks.

Figure 8. Emissions results from Dodge Spirits



Phase II Preliminary Emissions Results

During fiscal year 1994, the program performed 259 emissions tests on 75 alternative fuel vehicles and 102 emissions tests on 71 gasoline control vehicles. Table A-3 in the Appendix lists the number of each vehicle model included in the program and the number of tests done on each model. In fiscal year 1995, the program will perform more emissions tests on these vehicles, as well as on new vehicles. Once the new data are added to the data already gathered, the program will have the information needed to compare, with a high level of confidence, the emissions from vehicles running on reformulated gasoline to those from vehicles running on alternative fuels. To date, the program has completed about half of its planned agenda for testing emissions; the results presented below for each vehicle, therefore, are preliminary.

Results from Dodge Spirits

To date, the program has done the most extensive testing on Dodge Spirits, performing 172 emissions tests on 44 methanol flexible-fuel models and 61 tests on 43 standard gasoline models. As shown in Figure 8, all the results from these four-cylinder passenger cars are well below the Tier 1 standards for non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen.

When the flexible-fuel vehicles were tested on 85 percent methanol or 50 percent methanol, they emitted between 12 percent and 16 percent less carbon monoxide than the flexible-fuel vehicles did when tested on reformulated gasoline. Yet the flexible-fuel vehicles emitted 10 percent to 15 percent more carbon monoxide running on alcohol than did the dedicated gasoline Dodge Spirits running on reformulated gasoline.

The emissions of non-methane hydrocarbons and oxides of nitrogen were not significantly different between alcohol and reformulated gasoline for the flexible-fuel vehicles, but were significantly higher than emissions from dedicated gasoline Dodge Spirits running on reformulated gasoline. Note, however, that the emission level of non-methane hydrocarbons represents a class of pollutants rather than one specific compound. Therefore, the constituents of the non-methane hydrocarbon emissions from different vehicles may be quite different. For example, research presented at a recent conference of the Society of Automotive Engineers found that hydrocarbon emissions from the methanol fuel vehicles tested contained higher levels of formaldehyde than gasoline vehicles tested. However, the hydrocarbons from the gasoline vehicles contained higher levels of toxics such as benzene than the hydrocarbons from the alcohol fuel vehicles (Vaughn Burns et al., “Emissions with Reformulated Gasoline and Methanol Blends in 1992 and 1993 Model Year Vehicles,” SAE 941969, October 1994).

Results from Chevrolet Luminas

The average results from the six-cylinder Chevrolet Luminas were all below the Tier 1 emissions standards (see Figure 9), although results from individual tests may have exceeded the standards. With the exception of hydrocarbons, for the flexible-fuel vehicles, the emission levels from the alcohol tests were significantly lower than those from the tests for reformulated gasoline; the emissions of hydrocarbons among fuel types showed little variation.

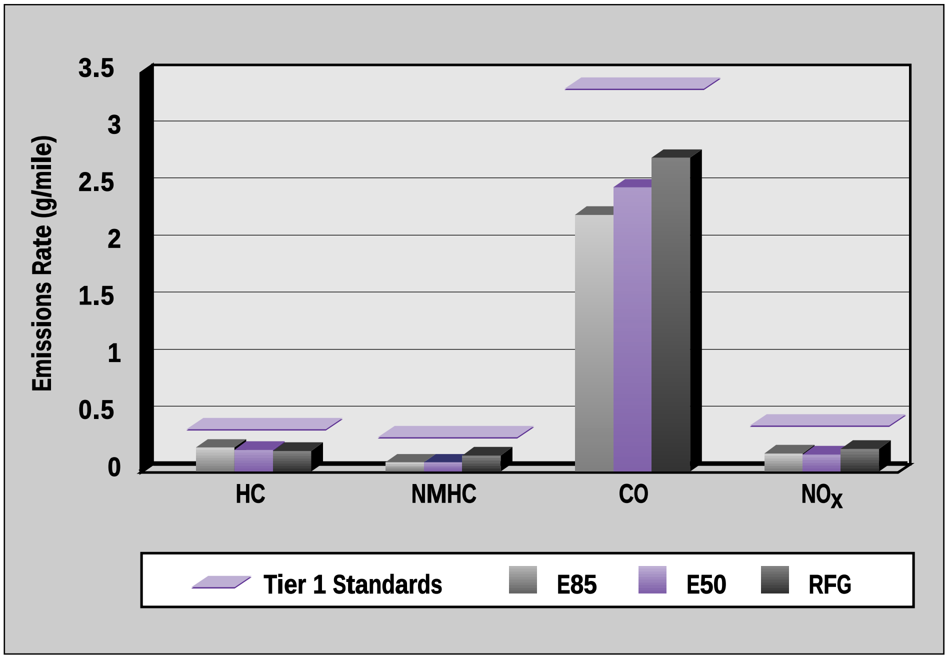


Figure 9. Emissions results from Chevrolet Luminas

When compared to the standard Lumina running on reformulated gasoline, however, the emissions from the flexible-fuel vehicles were far lower on all counts.

For the flexible-fuel vehicles, typically, the lowest average results came from the 85 percent ethanol tests, followed by the 50 percent ethanol tests, and then by reformulated gasoline. The standard Lumina showed the highest average emissions for every category of pollutant.

Results from Dodge B-250 Vans

Nearly every individual emissions data point collected so far for the

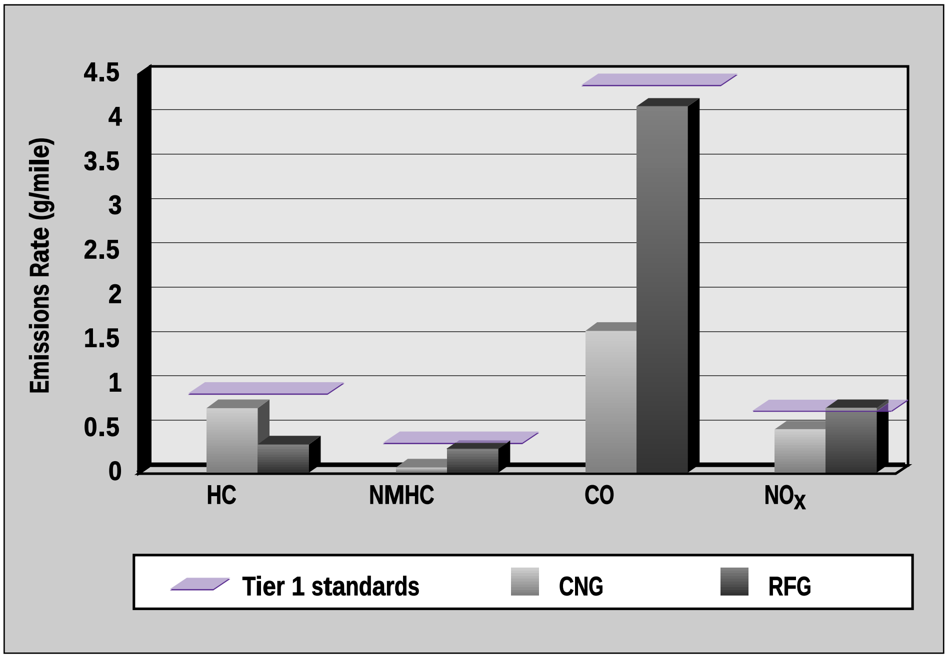
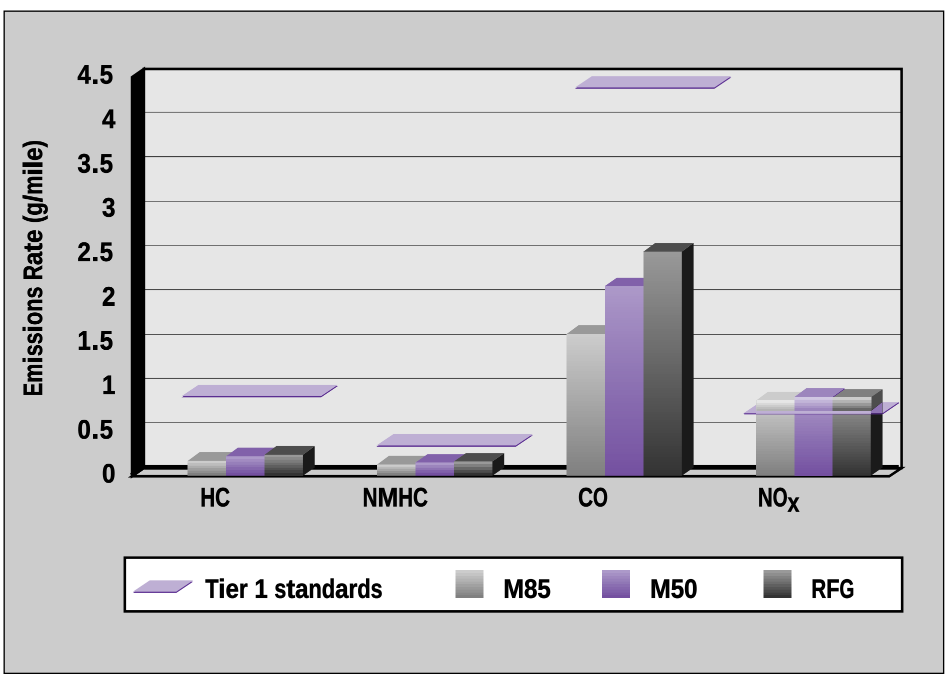


Figure 10. Emissions results from Dodge B-250 vans

Figure 11. Emissions results from Ford Econoline vans



dedicated vans operating on compressed natural gas met the Tier 1 standards, and all the average results are well below these standards. In contrast, individual results from the gasoline vehicles and even some of the averages did not meet Tier 1 standards (although they met the less stringent Tier 0 standards). The average results for the Dodge vans along with Tier 1 standards for light-duty trucks are shown in Figure 10. Because several of the vans using compressed natural gas have arrived at the emissions laboratories with fuel system leaks, test procedures have been modified to include a leak test similar to the evaporative tests performed on liquid fuel vehicles (see sidebar on page 18). These tests will show the extent of leakage from the compressed natural gas systems.

Results from Ford Econoline Vans

The methanol flexible-fuel Ford Econoline Vans are a relatively new addition to the emissions testing program. By the end of fiscal year 1994, 18 tests had been completed on 5 vehicles. The initial data points indicate a potential for reduced emissions when the vehicles operate on alcohol fuels (see Figure 11). Further testing will determine if these early results can be shown to be statistically significant.

Performance and Reliability

In the United States, manufacturers have produced alternative fuel vehicles for only a few years. In contrast, they have produced gasoline vehicles for more than 8 decades. The classical development curve for any technology shows that early in a product's development stage, problems with reliability tend to be very high, but these problems decrease dramatically as the product matures. We should expect, therefore, that the new kinds of vehicles in the program will experience more reliability problems than those with a long history of development.

These classical expectations are being borne out for the light-duty vehicles being tested. Early in the test program, the alternative fuel vehicles experienced more reliability problems than comparable gasoline vehicles. However, as data begin to accumulate on the newer models of the alternative fuel vehicles, a different picture is emerging (see Figure 12). The newer models seem to have achieved a higher level of reliability and performance than the earlier ones. This improvement probably results from making changes in the vehicle design and from basing service on experience with the earlier models. Changes made include:

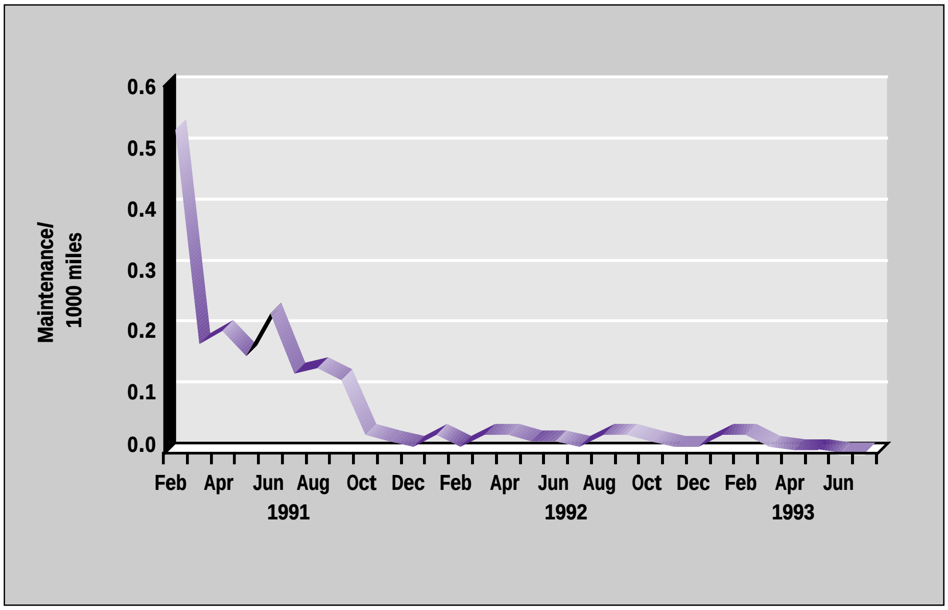
- Fuel system materials that are more compatible with alternative fuels now being used.
- The programming of the control computer for the engines of alternative fuel vehicles has been improved.
- The refueling connectors for compressed natural gas have been redesigned. (These connectors are now standardized.)
- The fuel-type sensor for the engine computer has been improved.
- More durable fuel injectors and fuel pump speed controllers are being used. (The Chevrolet Lumina uses a two-speed fuel pump.)
- On-line service information is now available to the repair technician.

The fuel system parts replacements from earlier and later model alternative fuel vehicles are tabulated in Table A-4 in the Appendix. The repair data collected indicate that repair technicians misdiagnosed problems in several instances. In some cases, various parts were replaced until driver complaints eventually stopped. In most cases, repairs were covered by the manufacturer's warranty, so excess downtime, not cost, was the burden presented to the fleet operator. Misdiagnoses and downtime for repairs may be reduced as repair technicians become familiar with alternative fuel vehicles. This familiarization process will take time because technicians are exposed to relatively few alternative fuel vehicles.

Fuel Economy

The program measures the fuel economy of the vehicles in the test fleet in two ways: by testing the vehicles on a chassis dynamometer and by

Figure 12. Methanol vehicle repairs reported: February 1991-August 1993



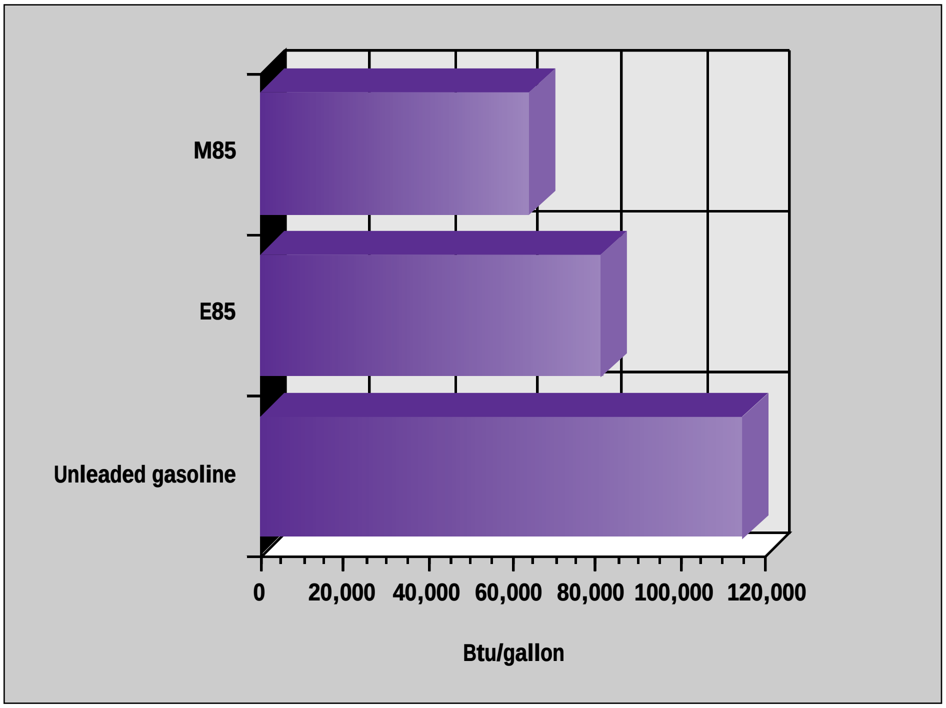


Figure 13. Energy content comparison

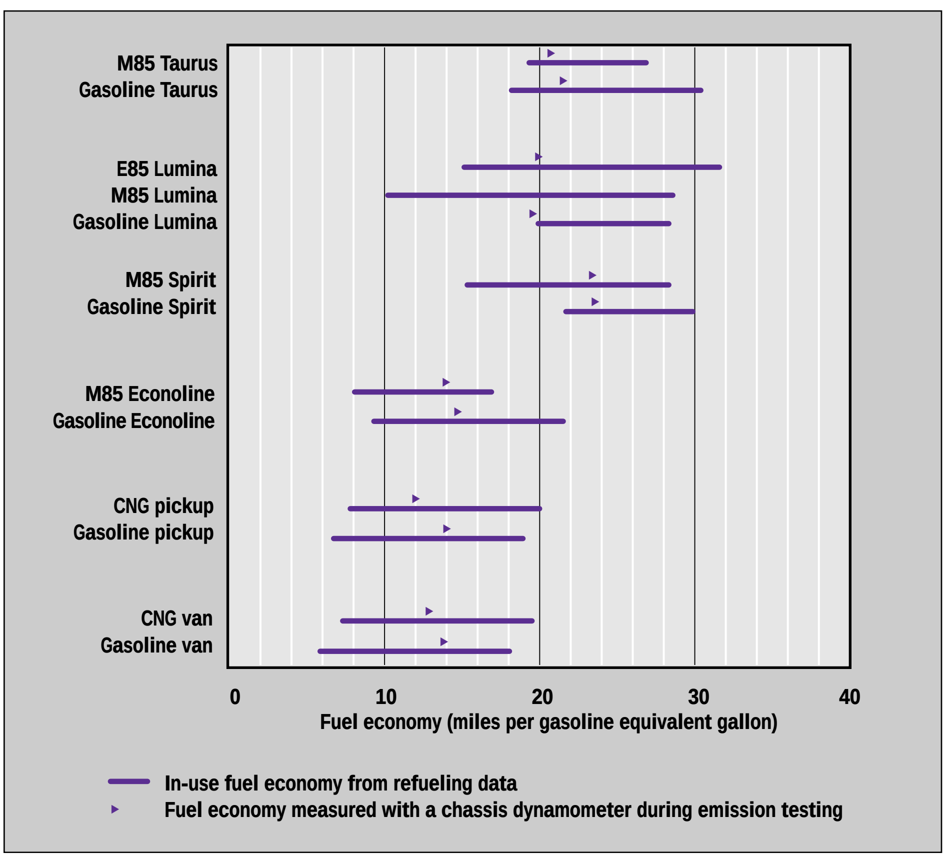
analyzing refueling records. All figures are reported as miles per gasoline equivalent gallon, which expresses the fuel economy on an equivalent energy basis. This compensates for differences in the energy content of each fuel type and uses the average energy content of unleaded gasoline as the basis for comparison—115,000 Btu per gallon (see Figure 13). One gallon of unleaded gasoline has the same energy content as 1.77 gallons of 85 percent methanol, and as 1.42 gallons of 85 percent ethanol.

During emissions testing, the chassis dynamometer tests provide information on fuel economy. The fuel economy tests provide a single number that is based on a specific "city" driving cycle. Closely controlling the fuel and operating conditions, the test laboratories take measurements on a number of like vehicles, which are then averaged into a single value. The dynamometer results are shown as points in Figure 14.

The program calculated the actual in-use fuel economy for the light-duty vehicles by using the 27,900 refueling records currently in the Alternative Fuels Data Center. During actual use, the fuel economy varies considerably because of factors such as driving cycle (stop-and-go city driving, highway driving, deliveries, or a combination of all three) and individual driving styles. An individual vehicle/driver combination generally has a fairly consistent fuel economy, but wide variations in fuel economy occur from vehicle to vehicle, site to site, and driver to driver.

Analysis of the in-use fuel economy is further complicated by the fact that the alcohol vehicles are flexible-fuel vehicles and may be fueled with gasoline at any refueling. This

Figure 14. Fuel economy by vehicle type



gasoline then mixes with the alcohol fuel left in the tank to create some unique mixture of alcohol and gasoline. To compensate, the program bases its fuel economy calculations only on instances where alcohol fuels were used for three consecutive refuelings. The range of results for in-use fuel economy for each vehicle type is shown as a line in Figure 14.

The figure shows that, on an equivalent energy basis, vehicles operating on alternative fuels have about the same fuel economy as those operating on reformulated gasoline.

Cost

Total cost for owning and operating a light-duty gasoline vehicle may generally range from 25 to 40 cents per mile. Total vehicle costs include costs for acquisition, maintenance, insurance, fuel, and oil. Results from the Federal alternative fuel fleet test program indicate that, for current prototype vehicle technologies and the immature fueling infrastructure, the costs for alternative fuel vehicles are slightly higher than the cost for gasoline vehicles. In the case of alcohol vehicles, the fuel costs are higher than gasoline, but the incremental cost for vehicle acquisition is relatively low. For natural gas vehicles the fuel costs are lower than gasoline, but the incremental cost for purchasing a natural gas vehicle is significantly higher.

Additional Acquisition Cost

The additional acquisition cost is the difference between the cost of a stock gasoline fueled vehicle and that of an alternative fuel vehicle. Currently, the modifications needed for alcohol vehicles add between $0 and $800. Compressed natural gas vehicles may add as much as $4,800 to the vehicle's cost. Typical vehicle modifications for alcohol vehicles include plastic or stainless steel fuel tanks and lines and special gaskets. High-pressure tanks and tubing are required for compressed natural gas vehicles. Some of the additional acquisition cost may be recovered when the vehicle is sold, but this depends on its final

Reformulated Gasoline

Spurred by the need for cleaner air and lower vehicle emissions, and working in concert with the automotive industry, refiners created a cleaner burning gasoline late in the 1980s. The term "reformulated gasoline" was coined in 1989 in response to proposals to include clean fuels requirements in the Clean Air Act Amendments. Today, the sale of reformulated gasoline is mandated in the nine smoggiest cities in the country, plus any cities that voluntarily opt in to the program.

Compared to standard gasoline, reformulated gasoline has a lower organic sulfur content, reduced aromatic concentrations, and a lower vapor pressure. It also has added oxygenates, which reduce carbon monoxide emissions while improving the octane quality of the gasoline. The most common oxygenates are ethanol, methyl tertiary butyl ether (a methanol-based ether), ethyl tertiary butyl ether (an ethanol-based ether), and tertiary amyl methyl ether.

To compare alternative fuels to clean-burning gasoline, reformulated gasoline was used as the base case in the emissions study. Both the State of California and the Federal Government have issued standards for reformulated gasoline. California-certified reformulated gasoline is used for the emissions testing presented in this report.

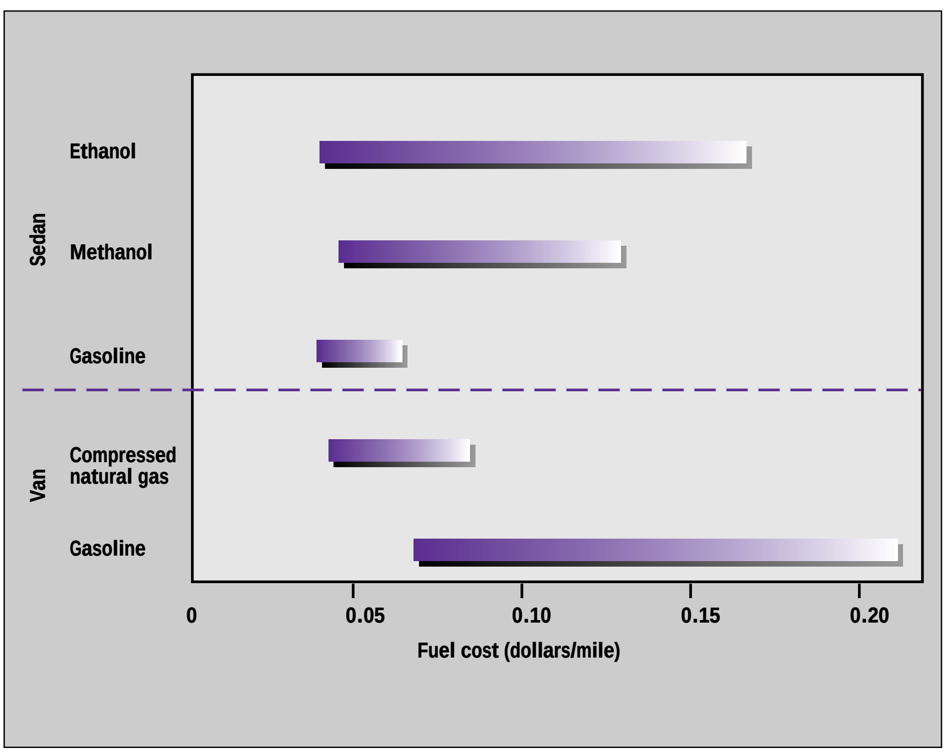
application and whether the alternative fuel is locally available.

Fuel Cost

Fuel cost varies greatly across the country, depending both on wholesale fuel cost and local tax treatment of the fuel. Wholesale fuel cost varies about 20 cents per equivalent gallon among cities. State and local tax treatment can vary by as much as 40 cents per equivalent gallon. Variations include taxing only the gasoline portion of an alcohol fuel, offering ethanol incentives of up to 40 cents a gallon, and taxing the entire fuel as if it were gasoline. This disparity in tax treatment has an impact on each fuel's ability to compete in the marketplace. In September 1994, retail fuel prices were approximately $1.10 to $1.50 per equivalent gallon for 85 percent ethanol, $1.20 to $2.00 for 85 percent methanol, $0.60 to $0.90 per equivalent gallon for compressed natural gas, and $1.00 to $1.30 for unleaded gasoline. Several industry newsletters, such as *Clean Fuel Vehicle Week*, *Oxy-Fuel News*, and *21st Century Fuels*, track both the wholesale costs and the tax treatment of various fuels on a weekly or monthly basis.

The regional variations in fuel cost combine with the fuel economy variations from vehicle to vehicle to produce a wide range of fuel costs per mile driven. Figure 15 shows the range of fuel cost per mile for alternative fuels and gasoline sedans and vans in the Federal fleet.

Figure 15. Range of fuel costs per mile, based on large regional variation in fuel cost and driver-reported miles per gallon



Oil Cost

Oil cost depends on recommended oil change intervals and the price of oil. Because alcohol vehicle manufacturers recommend more frequent oil changes, the oil cost for these vehicles is generally higher than for gasoline vehicles. Typical oil costs are about 1.3 cents per mile for alcohol fuel vehicles, and 0.7 cents per mile for gasoline vehicles. In some cases natural gas vehicles may have extended oil change intervals, which results in lower oil costs for natural gas.

Maintenance Costs

Most maintenance on the Federal test vehicles has been done under warranty at no cost to the fleet operator (except for lost time in service). Thus, the maintenance cost per mile is not available. In general, maintenance costs are expected to be marginally higher for alternative fuel vehicles than for gasoline vehicles for several reasons. Parts costs are higher for vehicles in limited production. Experience with the test fleet has also indicated that some maintenance costs are unique to the alternative fuel vehicles. Although fuel pump and injector problems have been common, they are decreasing as manufacturers gain experience with alternative fuels. These factors lead to the expectation that the long-term maintenance costs of alternative fuel vehicles should, with time, approach those of gasoline vehicles.

Fuel Cost per Mile Traveled

The average fuel cost for operating a vehicle can be determined by using the national average fuel cost and the average fuel economy based on controlled dynamometer testing. However, these figures will not necessarily apply directly to vehicles in use, but will provide a good relative comparison. The cost per mile for a specific vehicle will be strongly affected by factors that affect fuel economy (see previous section) and by the local fuel cost.

Figure 16 presents the average fuel cost per mile for alternative fuel sedans and vans.

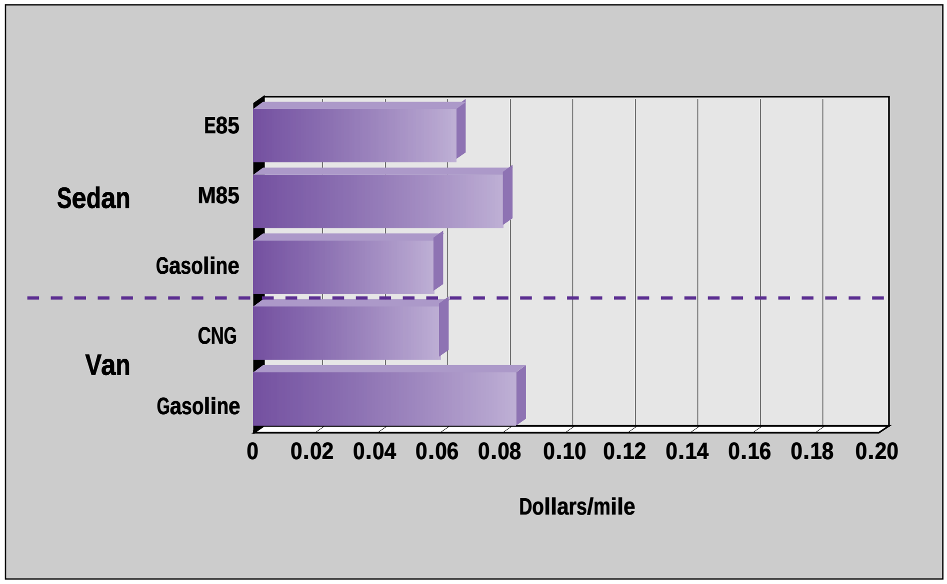
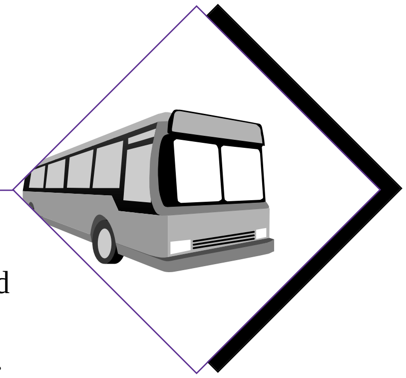


Figure 16. Average fuel cost per mile in 1994 for the light-duty alternative fuel vehicles in the program

Transit Buses



Overview

The transit bus program is designed to provide a comprehensive study of the alternative fuels currently used by the transit bus industry. The study focuses on the emissions levels, fuel economy, reliability, and operating costs of the various fuels and engines.

To obtain the detailed information needed for the study, the program selected transit agencies that met the following criteria:

- The transit agency must have test buses that represented the most current technology available at the time.
- The transit agency must have available control buses identical to the alternative fuel buses except for the fuel they use.
- The transit agency must be willing to supply detailed data on the vehicles for several years.

Using these criteria, the program chose to test buses in seven metropolitan areas: Houston, Texas; Miami, Florida; Minneapolis, Minnesota; New York, New York; Peoria, Illinois; St. Louis, Missouri; and Tacoma, Washington (see Figure 17). By design, these areas are located around the country, so that the buses can be tested while operating under different climatic conditions. The program is testing five alternative fuels—compressed natural gas, liquefied natural gas, methanol, ethanol, and B20, a blend of 20 percent biodiesel and 80 percent conventional diesel fuel.

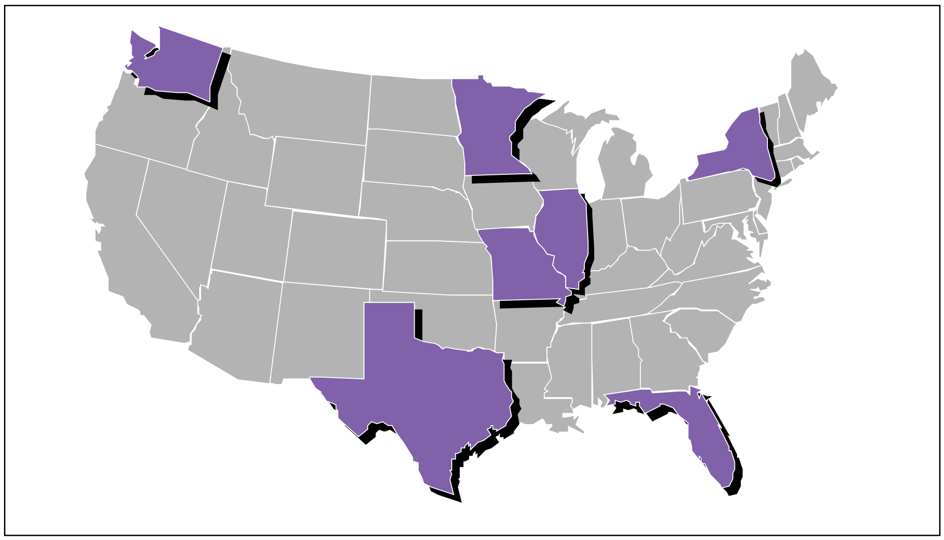


Figure 17. The program tests alternative fuel buses in seven municipalities across the nation.

B20 is not considered an alternative fuel under the Energy Policy Act of 1992. Figure 18 shows the number of test buses of each fuel type. At two of the sites, buses will be run on diesel with engines equipped with particulate traps, which will be compared to buses running on diesel without traps. The goal of the program is to test, at each location, a minimum of five buses running on a single alternative fuel and at least five control buses running on diesel. For example, in St. Louis the program is testing five buses running on biodiesel and five running on standard diesel. Table A-5 in the Appendix provides a summary of the transit buses in the program.

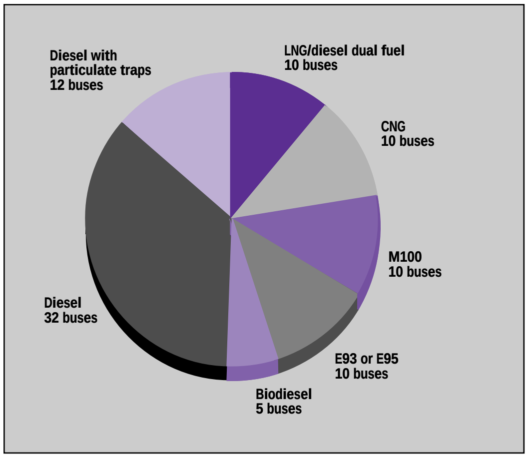


Figure 18. The number of test buses of each fuel type

A subcontractor collects data on maintenance, fuel, and added oil from each transit agency. The subcontractor then processes the data, converts them into a standard form for submission to the Alternative Fuels Data Center, and analyzes the results. The Alternative Fuels Data Center then makes the information available to the public through a series of data base queries designed to present the data in a concise and logical format.

West Virginia University uses its transportable chassis dynamometer to conduct emissions tests at each of the sites.

In addition to the operating data collected from each site, West Virginia University personnel visit each of the sites and conduct emissions tests on the buses using the university's transportable chassis dynamometer (shown in the photo).

With the exception of the biodiesel test buses, the alternative fuel buses in this program use the most common alternative fuel engines available from the heavy-duty engine manufacturers. These engines are:

- Detroit Diesel 6V92TA methanol engine
- Detroit Diesel 6V92TA ethanol engine
- Detroit Diesel 6V92TA pilot ignition natural gas engine
- Cummins L10 natural gas engine.

The biodiesel buses use biodiesel fuel in an unaltered Detroit Diesel 6V92TA engine. Each of the engines has a horsepower rating between 240 and 280. Buses in the program are 35-foot and 40-foot models manufactured by Mercedes, Flxible, Gillig, TMC, and BIA.

Detroit Diesel Corporation and Cummins have made extensive efforts to develop heavy-duty engines that run on alternative fuels and to introduce them into the transit bus market. The earliest of these engines were placed in the field as demonstration units to prove the concept of operation on the alternative fuels, and to identify areas for improvement. Since that time, both companies have improved their engines and emission control systems.

Emissions

West Virginia University's Department of Mechanical and Aerospace Engineering designed and constructed a transportable chassis dynamometer to test emissions levels from heavy-duty vehicles. The ability to transport this chassis dynamometer allows the program to perform a large number of on-site emissions tests on buses and heavy-duty vehicles around the country. Before the unit was built, other options were considered, such as transporting vehicles to existing stationary dynamometers, or removing engines and transporting them to existing facilities. Both options were rejected because of expense and vehicle downtime.

West Virginia University has available a detailed description of the test procedures and the facility design. Typically, the transportable chassis dynamometer is set up on the grounds of the test fleet or local transit agency and the selected heavy-duty trucks or buses are tested using the fuel in the vehicle at the time of the test. The dynamometer may be set up to operate inside or outside depending on the space available at the transit agency. Samples of the fuels (both alternative and diesel) being used at the site are collected and sent to a laboratory for analysis. The fuel analysis data are then sent to the Alternative Fuels Data Center.

The first transportable unit was built in 1991. The unit has tested transit buses and other heavy-duty vehicles nationwide since early in 1992. In 1994, a second unit was built; it will begin testing vehicles in 1995.

In 1994, personnel from West Virginia University's Department of Mechanical and Aerospace Engineering traveled to Miami, Minneapolis, Peoria, and St. Louis to perform emissions tests on 38 buses using DDC 6V92TA engines—engines designed to operate on 100 percent methanol, 95 percent ethanol, diesel, or biodiesel (no changes were made to the diesel engine for operation on biodiesel). They also traveled to Miami and Tacoma to perform emissions tests on 25 buses using Cummins L10 engines—engines designed to operate on compressed natural gas or diesel. They tested all the buses with the transportable chassis dynamometer using the standard Central Business District test cycle, a driving cycle devised to simulate the speeds, loads, and conditions experienced by buses during a typical route through a city's Central Business District. A summary of the results of the emissions tests for each engine type is provided below.

Detroit Diesel 6V92TA

Separate versions of the DDC 6V92TA engines are certified by the Environmental Protection Agency for operation on methanol and diesel. To run on methanol, the standard engine is modified to include a higher compression ratio, higher flow fuel injectors, the Detroit Diesel Electronic Controller, and methanol-compatible materials. This engine can be configured to run on 100 percent methanol, 85 percent methanol, or 95 percent ethanol; but the Environmental Protection Agency has not yet certified the engine for

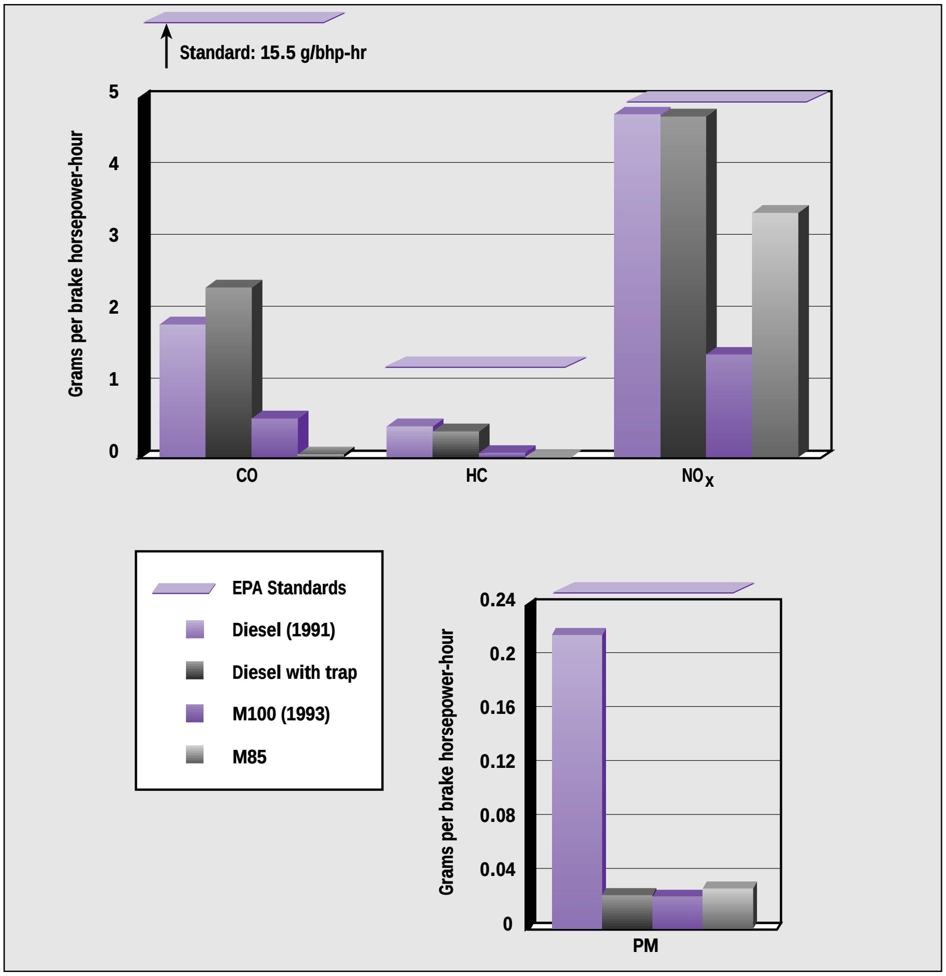
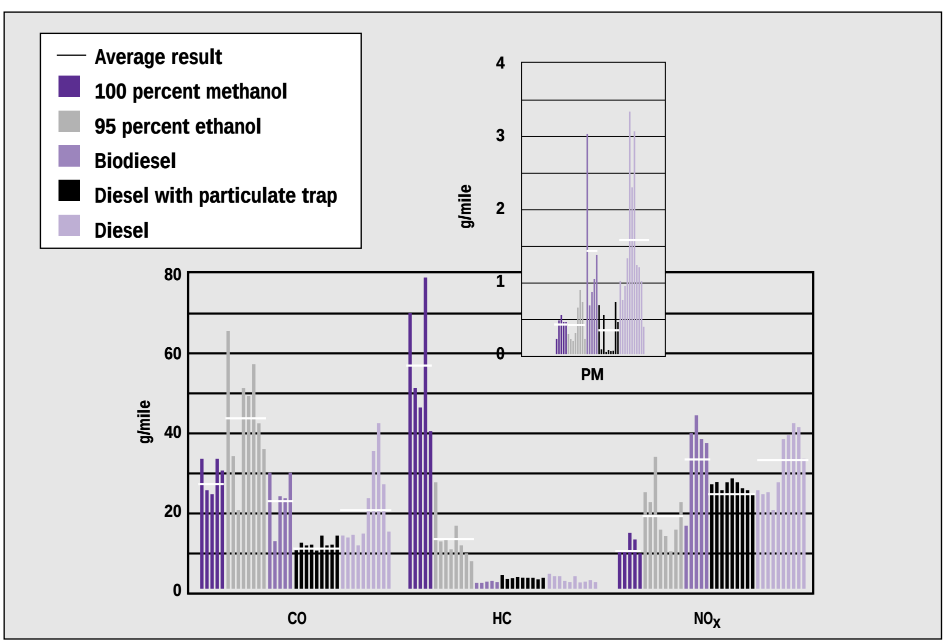


Figure 19 (above). Certification data from the DDC 6V92TA engine modified for methanol operation

Figure 20 (below). Emissions results from buses with DDC 6V92TA engines



operation on ethanol. Certification data for the methanol engine (Figure 19) show that the engine's emissions are well below the standards set by the Environmental Protection Agency.

The engine certification data are taken using an engine dynamometer and are therefore independent of the vehicle application. In contrast, the chassis dynamometer tests emissions from the vehicle over a specific driving cycle. The results of chassis dynamometer emissions tests on buses powered by DDC 6V92TA engines are shown in Figure 20. These are early test results and the data from the alcohol-fuel buses are quite variable from site to site and bus to bus. Nonetheless, we can make some general observations—buses running on alcohol emit far fewer nitrogen oxides and less particulate matter but significantly more hydrocarbons and carbon monoxide than do buses running on diesel. Note, however, that the hydrocarbon data for the alcohol-fuel buses are reported as organic material hydrocarbon equivalent, which includes a fraction of the unburned alcohol and aldehydes measured. The program is investigating several reasons, including whether the catalytic converters are functioning properly, for the increased emissions levels. Detroit Diesel Corporation has made recent improvements to the fuel injectors, which also may help improve emissions levels.

Cummins L10

The Cummins L10 buses tested so far in this program were demonstration units that were not certified by the Environmental Protection Agency. Cummins has since made several improvements to enhance the performance of its engines, and to reduce their emissions levels. The later versions of this engine have been certified by the California Air Resources Board and will be included in future testing.

Nonetheless, West Virginia University did perform chassis dynamometer tests on compressed natural gas and diesel control buses powered by Cummins L10 engines (Figure 21). As with the tests on the Detroit Diesel engines, these are early results and no definite conclusions can be drawn. But again, we can make some general observations. First, emissions levels from the diesel control buses appear to be more consistent from bus to bus than results from the buses running on compressed natural gas.

Second, as expected, the emissions of particulate matter from buses running on compressed natural gas are much lower than those from the diesel buses.

Third, some of the buses operating on compressed natural gas have far lower emissions levels of carbon monoxide than do the diesel buses. This may be partly because those buses with the low emission levels had odometer readings less than 20,000 miles, but the diesel controls for these vehicles are 2 years older with much higher odometer readings.

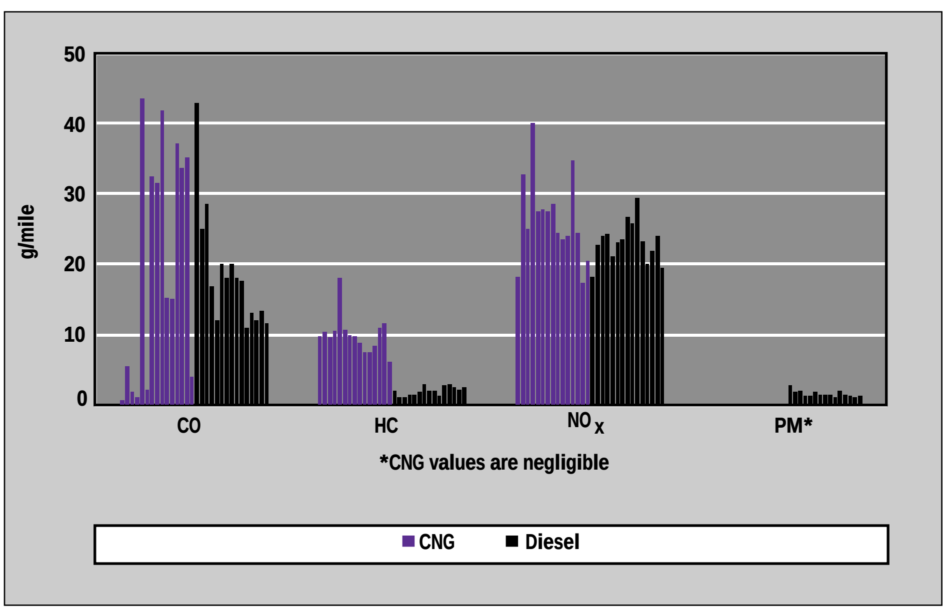
Finally, the compressed natural gas buses tended to have higher emission levels of hydrocarbons. It is likely that this difference in hydrocarbon emissions results primarily from methane emissions, which were not separately measured at the time of the tests. Because methane is considered to be nonreactive in forming ozone in the atmosphere, however, the Environmental Protection Agency has written new regulations in terms of non-methane hydrocarbons. West Virginia University plans to incorporate methane analyzers in the future.

Future Activities in Emissions Testing

The preliminary data on bus emissions have raised several questions:

- Why are the chassis dynamometer emissions so highly variable?
- What role does the condition of the bus/engine play in emissions?

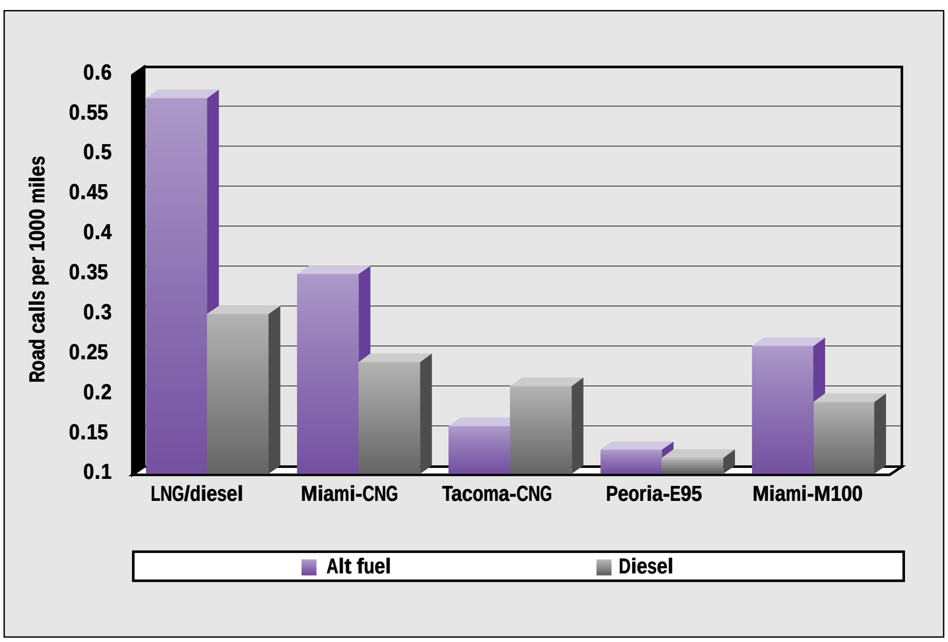
Figure 21. Emissions results from buses with Cummins L10 engines



Miles To Go Before We're Done

The goal of the program is to gather sufficient data on 10 buses for each fuel type, with five buses at one site and five at another. At this time, the program is approximately half complete. Some sites have reported a substantial number of data; others have just started to report data. Significant differences often emerge between sites as a result of different previous experience with the buses, different operating conditions, and different reporting procedures. Care should be taken in drawing conclusions from the program at this time. In the next report to Congress, the number of data available for analysis will more than double, and this will substantially raise the confidence level of the findings.

Figure 22. Road calls per 1,000 miles of operation[1]



[1] The diesel control buses in Miami are older than alternative fuel buses and have considerably more miles on the vehicles. Insufficient data are available to characterize the Minneapolis buses running on 95 percent ethanol and the St. Louis buses running on biodiesel.

- What is the cause of the relatively high carbon monoxide and hydrocarbon emissions levels?
- How can these high levels be corrected?

In September 1994, the National Renewable Energy Laboratory brought together a panel of experts from the engine manufacturers and others in the field of testing the emissions of heavy-duty vehicles. The panel reviewed the procedures followed by West Virginia University and the results seen so far. West Virginia University is already implementing some of the panel's recommendations. Representatives from Cummins and Detroit Diesel Corporation agreed to assist in the program by helping to identify the appropriate vehicles for testing, and by providing technical expertise when high emitters are encountered.

Performance and Reliability

One measure of reliability in a bus is the number of road calls that are required for every 1,000 miles that the bus travels. When the driver is prevented from completing his or her route because of a problem with the bus and calls for a replacement bus, a road call is recorded. Road calls encompass all types of events from an engine failure to simply running out of fuel.

The road calls per 1,000 miles of operation for the various buses at the different sites are shown in Figure 22.

Figure 22 indicates that the dual-fuel buses in Houston running on liquefied natural gas and diesel are experiencing considerably more road calls than the diesel controls. These road calls are largely due to the buses running out of fuel or to the system detecting a fuel leak and shutting down the bus. Note that the dual-fuel buses have a very small diesel fuel tank. If a fuel problem develops with the liquefied natural gas, the dual-fuel engines are designed to run on diesel as a backup. In this case, the bus would run out of diesel in a short time—the diesel fuel tank alone is not large enough to run the bus independently. The dual-fuel buses experienced more than four times the rate of road calls for "out of fuel" as did the diesel controls.

In the future, the program will add an additional site for buses running on liquefied natural gas. In this case, though, the buses will have different engines, to see if they have similar problems.

Buses running on compressed natural gas experienced a higher rate of road calls than their diesel controls at Miami, but a lower rate at Tacoma. However, total mileage accumulated on the Miami compressed natural gas buses is quite limited at this time. This also points out the need for two sites per alternative fuel and the need to average data over many miles.

Road calls for the Peoria buses running on 95 percent ethanol appear comparable to the diesel control buses with particulate traps.

Data from the Miami buses running on 100 percent methanol show a higher rate of road calls than their diesel counterparts. This difference is primarily because of problems with fuel systems and with stalling engines. However, these data are based on a total of less than 200,000 miles traveled. More miles are needed to confirm the results. The program has recently added a second site—New York (Triboro)—at which to test more buses running on 100 percent methanol. Data from the new site will be compared to the Miami results.

Fuel Economy

Fuel economy and fuel costs are very important to transit agencies because these costs represent a large portion of the operating cost of a transit bus: approximately half of the operating cost of a diesel bus, and more than half for some alternative fuel buses.

The fuel economy from engine dynamometer tests and the range of in-use fuel economies is shown in Figure 23 for each site. Expressing the fuel economy in miles per diesel equivalent gallon allows for a direct comparison of the relative energy efficiency of the various alternative fuel engine technologies.

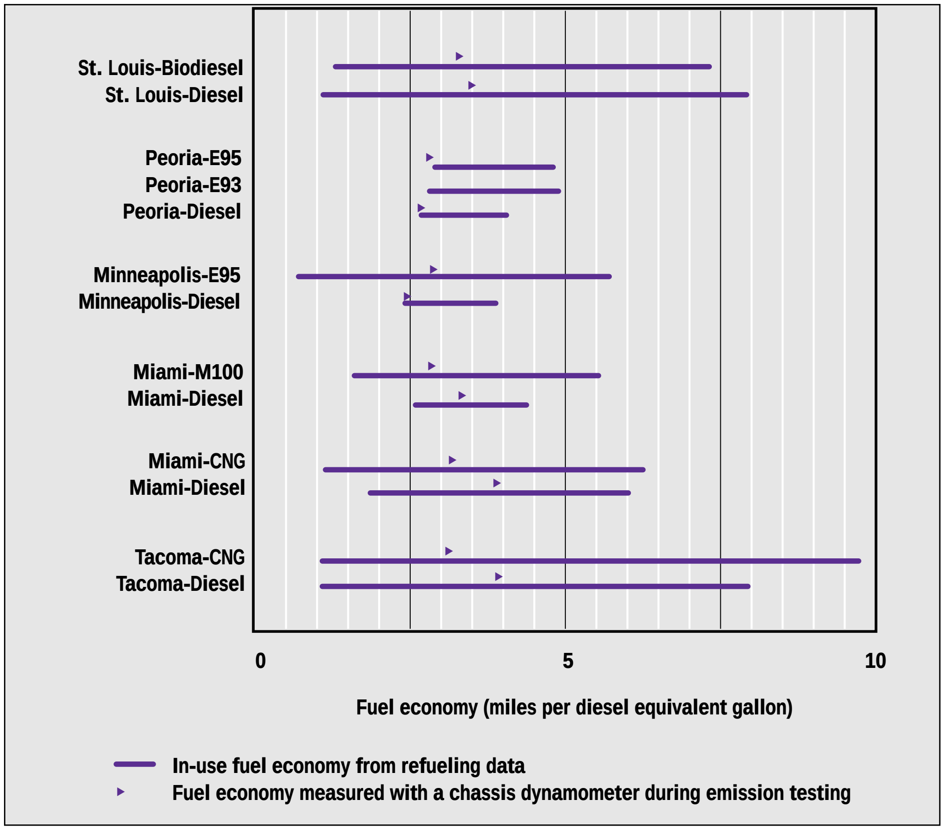


Figure 23. Bus fuel economy, expressed as miles per diesel equivalent gallon

Variability of fuel economy is different for each site. This variability may result from differences in driving cycles from bus to bus and from site to site. In general, sites with a tight range of fuel economies for the diesel buses also have a tight range for the alternative fuel buses. The dynamometer results (which were all obtained using the Central Business District driving cycle) are relatively consistent throughout the test fleet. This strongly indicates that the variations in the in-use results are probably due to driving cycles. Because the dynamometer results are consistently below the average in-use results, the Central Business District driving cycle may not be representative of the actual driving cycles of the test buses.

The liquefied natural gas engines at Houston operate on a compression-ignition cycle; the diesel fuel is used as a "pilot ignition" source to ignite the natural gas. An average fuel economy for these buses was calculated by summing the amount of liquefied natural gas (in diesel equivalent gallons) and diesel burned in the buses over time, and dividing that sum by the total miles logged. The average fuel economy for the liquefied natural gas buses (3.1 miles per diesel equivalent gallons) was approximately 14 percent less than that of their diesel counterparts. Part of this reduction may be attributed to the approximately 860 pounds of extra weight of the liquefied natural gas/diesel dual-fuel buses, but the majority is most likely attributed to the engine design or factors such as differences in driving cycles. It is interesting to note that when the dual-fuel buses were operating in their "backup" mode of diesel only, the fuel economy was within 1 percent of that of the control buses. This shows that the extra weight of the dual-fuel buses does not make a major contribution to the difference in fuel economy.

The compressed natural gas engines at Miami and Tacoma are spark-ignited throttle engines; the diesel engines are unthrottled compression-ignition engines. When a diesel compression-ignition engine is redesigned into a spark-ignition engine running on natural gas (as is the case with all the compressed natural gas engines in the program), there is an inherent loss of efficiency because of pumping losses. Pumping losses represent the amount of energy required for the engine to draw in air during the intake cycle. An unthrottled diesel engine has minimal pumping losses, whereas a spark-ignited engine with a throttle has significant pumping losses. Also, the compressed natural gas engines have a lower compression ratio than their diesel counterparts: 10.5:1 for the compressed natural gas engines versus 16.3:1 for the diesel engines.

An additional disadvantage for the compressed natural gas buses is their weight—they weigh about 3,900 pounds more than their diesel counterparts. This weight penalty can largely be attributed to the weight of the compressed natural gas tanks, and results in about a 15 percent increase in the curb weight of a bus (the diesel control buses have a curb weight of approximately 27,000 pounds). These three factors led to the expectation that energy efficiency might be significantly reduced. A difference in the fuel economy of the compressed natural gas and diesel buses was observed in the average results and in the dynamometer results. The fuel economy of the compressed natural gas buses was about 10 percent to 20 percent lower than that of their counterparts.

The alcohol buses also suffer from weight penalties. The alcohol option results in a weight penalty of between 1,000 and 1,500 pounds, depending on the tank's capacity. In addition, the alcohol buses at the

Miami site have an additional weight penalty of 1,200 pounds, which is attributed to options and specifications unrelated to the alcohol fuel engine. This extra weight was expected to reduce the fuel economy of the alcohol buses.

In addition, the alcohol buses have very high compression ratios (more than 20 to 1), which were expected to lower fuel economy because of friction losses such as piston side loading. The results to date, however, indicate that the alcohol fuel buses at all the sites are performing very well, delivering fuel economy comparable to that of the diesel control buses. The weight and compression ratio penalties may not be as significant as the pumping losses caused by throttling. Both the 95 percent ethanol and the 100 percent methanol engines at Peoria, Minneapolis, and Miami are unthrottled compression-ignition engines, meaning that they do not suffer from the same pumping loss penalties as the compressed natural gas buses. Also, the diesel control buses at Peoria are equipped with particulate traps, which are known to lower fuel economy slightly.

Biodiesel buses exhibited approximately 7 percent lower average fuel economy than the diesel control buses, but the range of their fuel economies overlapped considerably. Because the fuel economies quoted are already based on diesel equivalent gallons to eliminate any differences in fuel energy content, this drop was not expected. Research to determine the cause of this drop is under way.

In summary, the fuel economy results are in line with expectations from the various engine technologies, with the possible exceptions of the liquefied natural gas dual-fuel engine, and the biodiesel buses, where the reason for the lowered fuel economy is not readily apparent.

Cost

The cost of operating alternative fuel buses versus their diesel counterparts can be broken down into three primary categories:

- Additional acquisition cost
- Fuel cost
- Maintenance cost

Each component of the operating cost is covered in the following sections.

Because transit buses are stored and refueled centrally in facilities owned and operated by transit agencies, the capital and operating costs for any changes made to a facility to accommodate alternative fuel buses is also an important part of the overall cost of operating with alternative fuels. The capital and operating costs for new facilities or modifications to existing facilities to accommodate alternative fuel vehicles vary dramatically, even for one type of alternative fuel. These costs include changes such as installing new refueling equipment or installing monitoring and ventilation equipment. The costs are affected by the size of the agency and the state and local building codes. The program is currently evaluating representative capital costs and will present them in future reports. However, at this time, compressed natural gas and liquefied natural gas facilities appear to have the highest capital costs.

Additional Acquisition Cost

At this time, buses running on alternative fuels tend to be more expensive than those running on diesel. Higher engine costs represent a significant portion of this increased expense. Because these engines are developmental, the engine manufacturers charge about $25,000 to $30,000 more for an alternative fuel engine than for a diesel engine. We expect that, as their production volume increases, the cost of alternative fuel engines will begin to approach those of their diesel counterparts. There is, however, insufficient information to indicate if they will equal the cost of diesel engines some time in the future. Biodiesel buses are the exception to the rule. Because the buses running on biodiesel in this program use conventional diesel engines, there is no additional acquisition cost.

Also, alternative fuel buses are more expensive because their fuel tanks cost more. These additional costs can run from $5,000 for a bus operating on 95 percent ethanol to around $20,000 for one operating on compressed natural gas. Again, fuel tanks represent no additional expense for buses running on biodiesel.

Fuel Cost

In September 1994 the price paid for a gallon of diesel fuel by the transit agencies varied from about 47 cents to 65 cents. The price paid per diesel equivalent gallon varied considerably for the alternative fuels. The price paid for compressed natural gas was the lowest, at 58 cents to 69 cents per diesel equivalent gallon (this price excludes the cost of the electricity needed to compress the fuel—the program is currently calculating these costs and will include them in future reports). At $2.29 per diesel equivalent gallon, 100 percent methanol was the most costly of the alternative fuels in the test program. The price paid for 95 percent ethanol was about $1.76 per diesel equivalent gallon. Early in 1994 the Peoria Transit agency switched from using 95 percent ethanol to 93 percent ethanol (93 percent ethanol, 5 percent methanol, and 2 percent kerosene) to take advantage of a 43 cent per gallon “blenders credit,” which lowered their fuel cost to $1.19 per diesel equivalent gallon. The biodiesel used in Missouri and the combination of liquefied natural gas and diesel used in Houston each cost about $1.00 per diesel equivalent gallon.

In general, the prices of alternative fuels have been more variable than those of diesel fuel, both regionally and over time. For example, compressed natural gas prices differ significantly from region to region and methanol prices nationwide have been volatile recently.

Maintenance Cost

Maintenance costs are being tracked on all the buses. Copies of all the work orders and parts replaced are received from the transit agency. The work performed and parts replaced are coded by type of work (scheduled maintenance, unscheduled maintenance, road calls, and configuration changes to the buses), as well as by vehicle subsystem such as engine and fuel system.

A few words of caution are necessary in using the data. As more miles are logged by the test vehicles, a better average maintenance profile emerges from the data. Also, comparisons of maintenance data from different agencies should not be made because each agency has a different system for recording and submitting data. Finally, the maintenance cost data do not include warranty work performed on the buses because the agencies do not bear the cost of this work.

According to the limited number of data available at this time, maintenance costs for the Houston buses that run on liquefied natural gas and diesel have been considerably higher than for the control buses. This is partly due to problems with the gas injectors and with dirt in the fuel. Both of these problems were being rectified by the engine manufacturers and by Houston Metro. Fuel system leaks were also a source of problems.

The Miami buses running on methanol also have slightly higher maintenance costs related to the fuel system. These higher costs are currently being investigated. The addition of New York as a second methanol site will aid in the cost analysis of methanol buses.

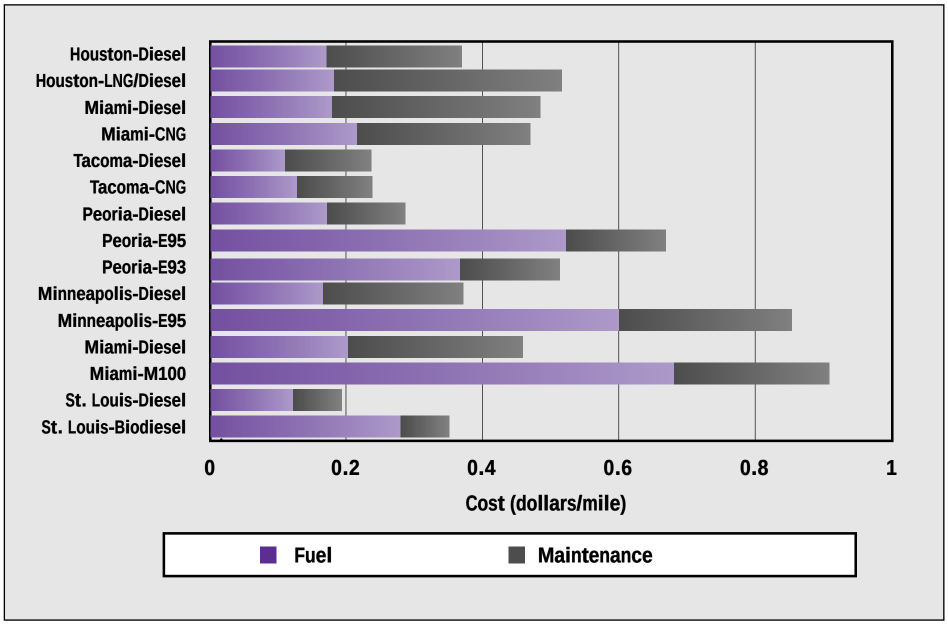


Figure 24. Bus fuel and maintenance costs per mile traveled (assumes labor rate of $15 per hour)

Maintenance costs for Tacoma compressed natural gas and Peoria ethanol buses are comparable to those of the diesel controls.

Cost per Mile Traveled

Figure 24 shows the fuel and maintenance costs per mile traveled. The fuel cost per mile was calculated using the average in-use fuel economy and the actual fuel cost paid by the transit agencies. The fuel and maintenance cost per mile for test buses running on compressed natural gas has been about the same as those for buses running on diesel fuel. However, the analogous costs for all of the buses using alcohol fuel and buses using biodiesel have been about twice as high as the costs for buses using diesel. The costs for liquefied natural gas/diesel buses have been about one and one half times those for their diesel counterparts.

Heavy-Duty Vehicles

Overview

The heavy-duty program collects data on two types of vehicles: medium-size commercial delivery vans and large trucks. Figure 25 shows the locations of the heavy-duty vehicles in the test program. Gasoline is the standard fuel for commercial delivery vans; diesel is standard for large trucks. The vehicles included in the program are listed in Table A-6 in the Appendix. Figures 26 and 27 show the number of test vehicles of each fuel type for large trucks and delivery vans, respectively. The large trucks in the program are used for various purposes such as picking up garbage or transporting goods over long distances (known as line-haul operation). The trucks' driving cycles are distinctly different, depending on how they are used. Figure 28 depicts the function of the test trucks (called vehicle "vocation"). The program has made an effort to include in the testing as many typical large truck vehicle vocations as possible.

Because large trucks are usually very expensive, the ability to test a particular vehicle vocation depends primarily on the availability of willing cosponsors. Private fleet owners or state or local governments are sharing the high cost of the test vehicles in the program; on average, the program costs are being split approximately evenly.

As alternative fuels become more widely used, state and local governments and private fleets are increasingly interested in sponsoring alternative fuel vehicle programs. The program goal is to cosponsor the use of as many of the large alternative fuel engines (those that are now commercially available from original equipment manufacturers) as possible, and to take data to track the engines' cost and performance. The sidebar on page 42 highlights the alternative fuel engines currently in production or preproduction by original equipment manufacturers. In general, these engines are dedicated to a spe-

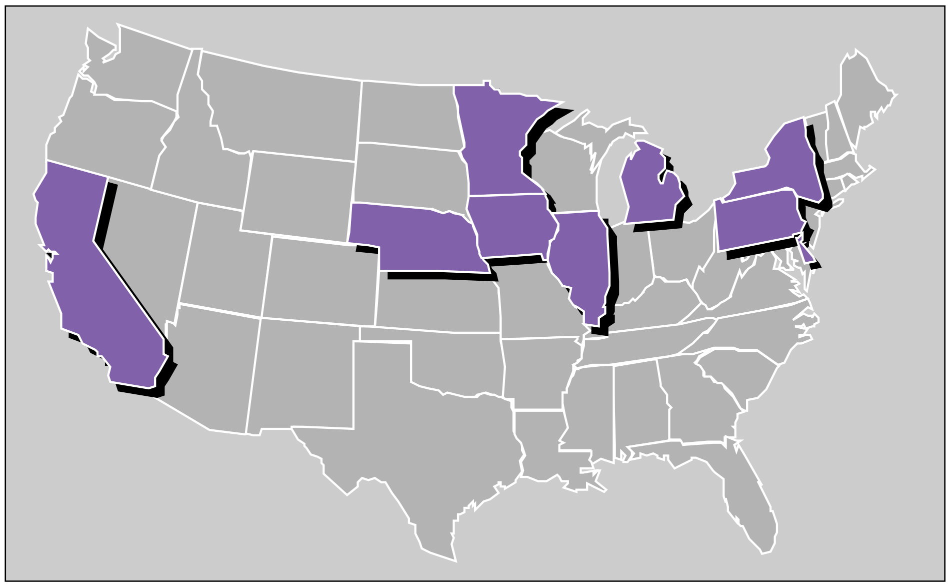


Figure 25. Locations of heavy-duty vehicles in the test program

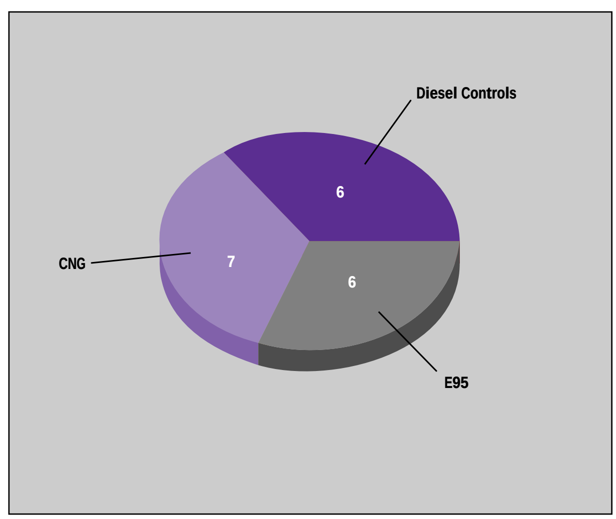


Figure 26. Number of large trucks of each fuel type

Heavy-duty Alternative Fuel Engine Availability

Three original equipment manufacturers—Detroit Diesel Corporation, Cummins Engine Company, Inc., and Caterpillar Inc.—now have alternative fuel heavy-duty engines in production. Below is a list of the engines made by each of these companies and their use.

Manufacturer	Model	Fuel	Horsepower Range	Vocations
Detroit Diesel	6V92	E95	250-300	Bus, large truck
Detroit Diesel	6V92	M85	250-300	Bus, large truck
Detroit Diesel	Series 50	Natural gas	250-300	Bus, large truck, garbage packer
Cummins	L10	Natural gas	240-260	Bus, large truck, garbage packer
Caterpillar	3306	Natural gas	250	Bus, medium truck, garbage packer

The natural gas engines can be run on either compressed natural gas or liquefied natural gas.

In addition to the engines that are currently in production, each of these companies has heavy-duty engines that are in the pre-production development and demonstration phase. The pre-production engines are listed below.

Manufacturer	Model	Fuel	Horsepower Range	Vocations
Detroit Diesel	Series 60	Natural gas	300-400	Large truck
Detroit Diesel	Series 40	Natural gas	250-300	Medium truck
Detroit Diesel	Series 30	Natural gas	200-250	Medium truck, school bus
Cummins	C8.3	Natural gas	250	Medium truck
Cummins	B5.6	Natural gas	N/A	Medium truck, school bus
Caterpillar	3406	Natural gas	350	Large truck

Most of these engines are designed to be used in transit buses or large trucks such as tractor-trailer line-haul trucks or large municipal trucks (such as dump trucks and plows). However, some engines (with the vocations labeled “medium truck” above) are being targeted for the lighter end of the heavy-duty vehicle spectrum. Representative vocations for these include delivery trucks, lighter municipal trucks, and 20-foot box trucks. Some of these medium truck engines are also being built for school buses.

A Quieter Garbage Truck

New York City has operated six compressed natural gas garbage packers for more than 2 years with excellent results. Drivers appreciate the significantly lower engine noise levels of the compressed natural gas vehicles compared to their diesel counterparts. These are the only garbage packers in New York City where the driver and assistant can easily talk to each other in the cab.

As a result of the excellent performance and driver acceptance, the New York City Department of Sanitation has ordered ten additional compressed natural gas garbage packers. Five will be equipped with Detroit Diesel Corporation Series 50 engines and five will be equipped with Caterpillar 3306 engines.

cific fuel type. Therefore, by testing a variety of engines, the program is also testing a variety of alternative fuels.

The program collects data on the fuel and oil consumption, maintenance, performance, and emissions of alternative fuel vehicles and control vehicles of the same type that operate on conventional fuels. The fleet operators provide all except emissions data to the Alternative Fuels Data Center. The vehicle emissions are measured using the transportable chassis dynamometer operated by West Virginia University. These data are also transferred electronically to the data center, which makes the information available to the public in various ways, including via an Internet option.

The program is also currently tracking two commercial van delivery fleets: the Federal Express

Detroit Diesel Corporation methanol engine

CleanFleet, and the United Parcel Service fleet. The Federal Express CleanFleet uses several alternative fuels (compressed natural gas, propane, and 85 percent methanol); the United Parcel Service uses only compressed natural gas. Comparisons are drawn between the alternative fuel vehicles in these fleets and vehicles with similar engines that operate on unleaded gasoline or reformulated gasoline.

In addition to the data collection program described above, the Department of Energy also manages a grant program that supports states in their purchases of alternative fuel heavy-duty vehicles. The vehicles in the grant program are located all across the country; they represent vehicle vocations that range from street sweepers to school buses. The program is collecting some data from the grant program, which will be added to the Alternative Fuels Data Center. The locations of the vehicles in the grant program are shown in Figure 29, with additional details in Tables A-7 through A-9 in the Appendix.

Emissions

Federal Express CleanFleet

In the CleanFleet program, 36 vans are undergoing emissions tests. The first round of emissions tests was performed after approximately 4,000 miles of driving. Figures 30 through 32 present the results. The program has conducted two additional rounds of emission tests: a second round of tests after the vans have driven approximately 14,000 miles and a third round at the end of the project. The results of these additional rounds of emissions tests are currently being analyzed. The program tested three vans from each combination of vehicle manufacturer and fuel type.

The CleanFleet vans use liquid and gaseous alternative fuel technologies that were available for commercial service in 1992, met Federal Express operations requirements, and had the backing of the three manufacturers—Ford, Chrysler, and General Motors (Chevrolet). Aspects of the vehicle technology pertinent to exhaust emissions follow.

The propane gas vans from Ford and Chevrolet were gasoline production vans retrofitted to burn propane gas. The Chevrolet vans were equipped with a special catalytic converter designed specifically for vehicles operating on propane. The Ford vans, however, used a catalytic converter designed for vehicles burning gasoline.

The compressed natural gas vans also represent a range of technologies. The Chevrolets are gasoline vans modified to run on the gaseous fuel and use an Englehard catalyst optimized for

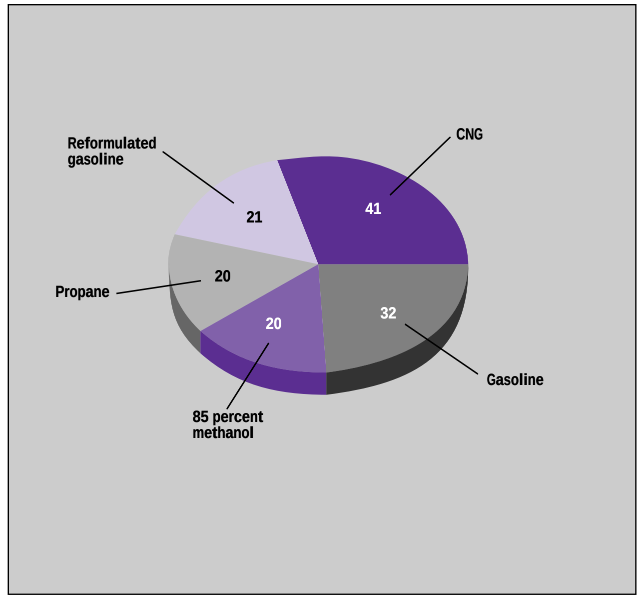


Figure 27. Number of delivery vans of each fuel type

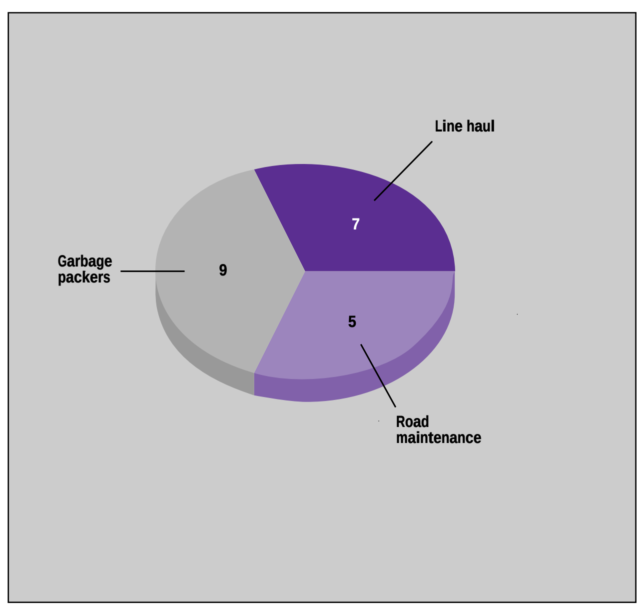


Figure 28. Vocation of large trucks in the program

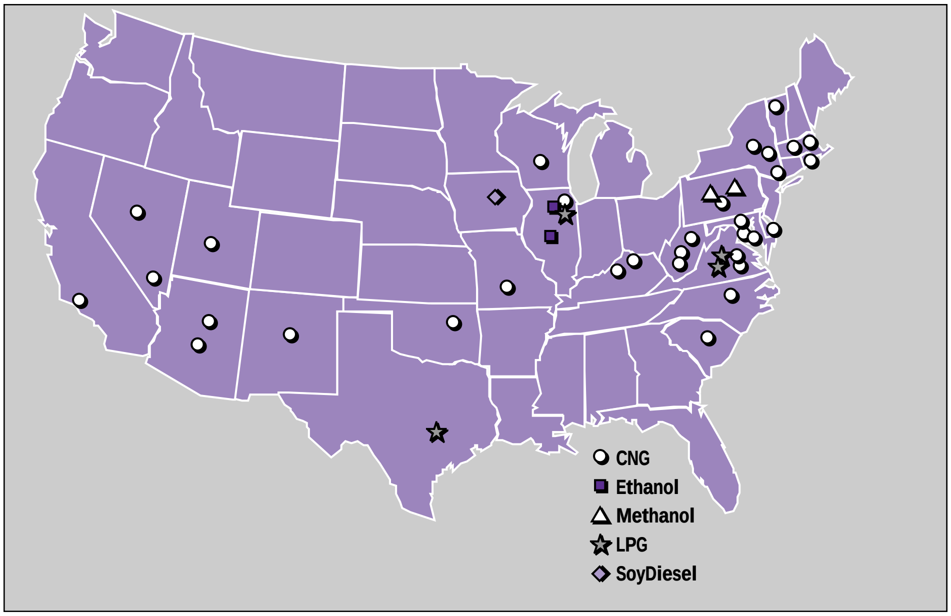
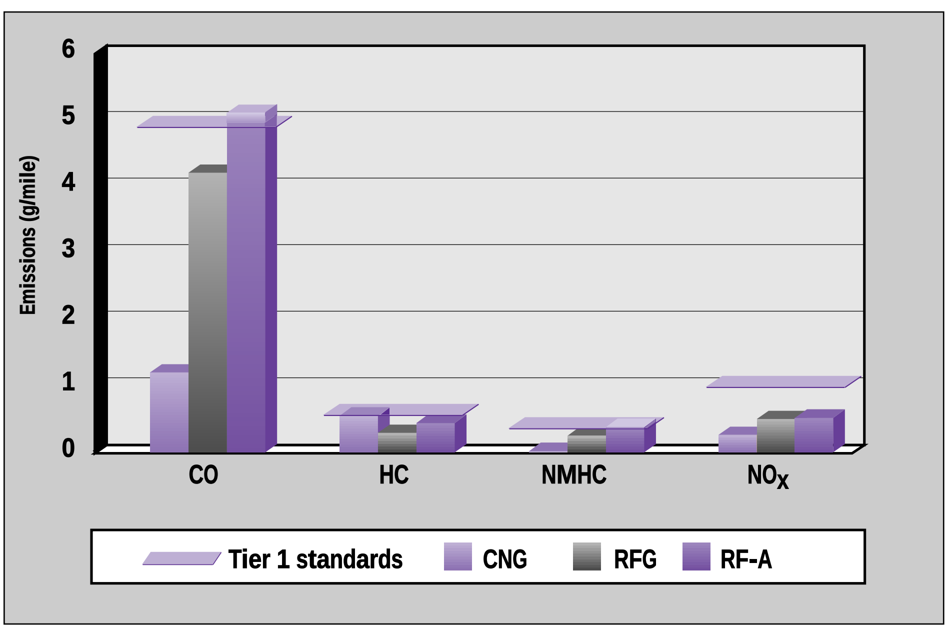


Figure 29. Locations of heavy-duty vehicles in the grant program

Figure 30. Emissions results for CleanFleet Dodge delivery vans



compressed natural gas. The Ford vans have an engine optimized for compressed natural gas and a catalyst system designed for gasoline vehicles. The Dodge vans, which are among the first production vans to run on compressed natural gas, use a catalyst system tailored for use with natural gas vehicles.

The methanol vans are Ford flexible-fuel vans with a gasoline catalyst system. During the CleanFleet demonstration, the vans are run strictly on 85 percent methanol.

The reformulated gasoline and control vans are standard, gasoline-powered, production vans.

The California Air Resources Board conducted the emissions tests using a chassis dynamometer running the Federal Test Procedure. Within the CleanFleet program, reformulated gasoline was considered to be an alternative fuel. Industry average standard unleaded test gasoline (RF-A) was used in the control vehicles for comparison to the alternative fuel vehicles.

Figures 30 through 32 show that several of the vehicles demonstrated statistically significant improvements over the gasoline control vehicles. The CleanFleet compressed natural gas vehicles emitted an average of 65 percent to 80 percent less carbon monoxide than vehicles running on unleaded gasoline. These vehicles also had 70 percent to 95 percent lower non-methane hydrocarbon emissions. Emissions of oxides of nitrogen were mixed, ranging from 50 percent less than gasoline for the Dodge vans to about 20 percent more for the Ford vans.

As shown in Figure 32, the Ford vans running on 85 percent methanol had lower emissions of all four of the measured pollutants—from about 20 percent lower oxides of nitrogen emissions to about 50 percent lower total hydrocarbon emissions.

The propane vans in the CleanFleet emitted about 50 percent less carbon monoxide but about 50 percent more hydrocarbons than their gasoline-powered counterparts. Emissions of oxides of nitrogen were about 60 percent less than gasoline vans for the Chevrolet vans, but about 50 percent more for the Ford vans.

Because few of the vehicles in the CleanFleet program were fully optimized for the alternative fuels, these emissions results are encouraging.

Large Trucks

During fiscal year 1994, West Virginia University used its transportable chassis dynamometer to measure emissions from the New York City Department of Sanitation's compressed natural gas garbage packers, Archer Daniels Midland's 95 percent ethanol and diesel control line-haul trucks in Illinois, and Hennepin County, Minnesota's 95 percent ethanol and diesel control snowplows.

Emissions Results from Compressed Natural Gas Garbage Packers

Compressed natural gas garbage packers with Cummins L10 engines, which operate in New York City, have automatic transmissions and were tested using the standard Central Business District driving cycle. The emissions results from these vehicles were promising but mixed.

Particulate matter emissions from the compressed natural gas trucks were very low—86 percent to 92 percent less than emissions from comparable diesel trucks. This appears to be an inherent advantage of natural gas fueled engines. More recent versions of compressed natural gas engines are attaining a 95 percent reduction in particulate matter emissions when compared to equivalent diesel engines.

The emissions of oxides of nitrogen from these uncertified prototype compressed natural gas engines were not as encouraging. The level of oxides of nitrogen emissions was approximately twice that from diesel. However, it must be noted that these

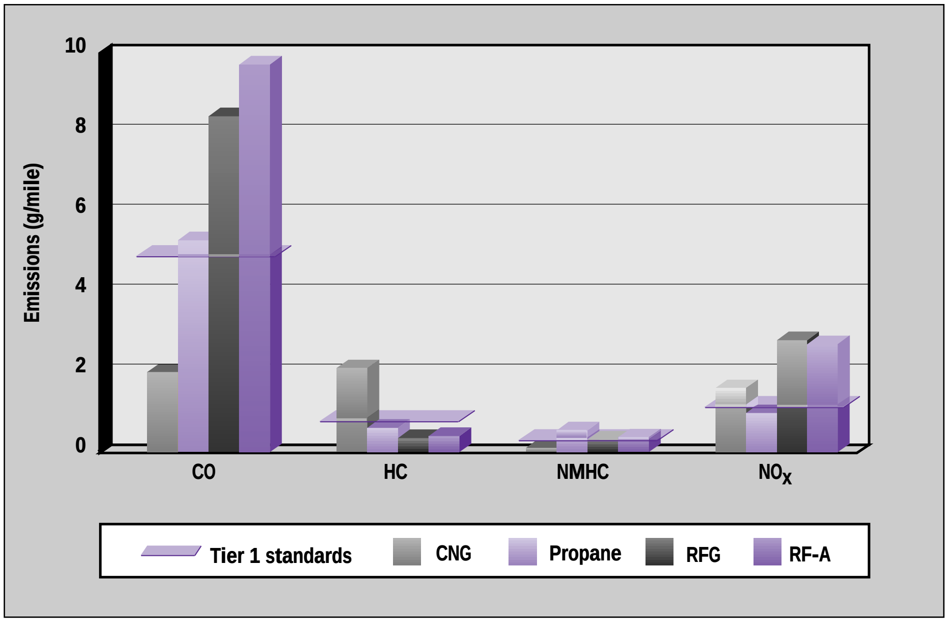
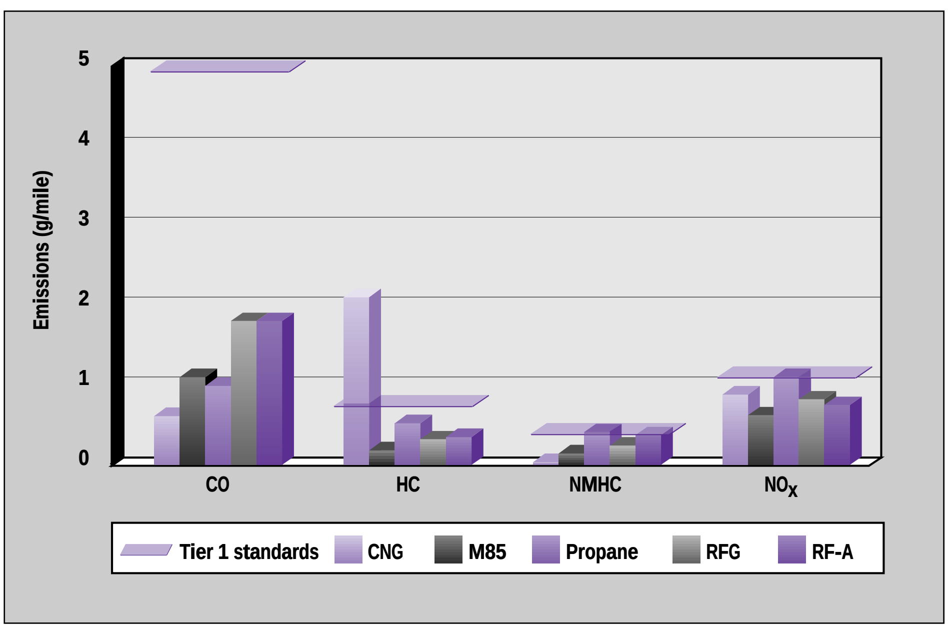


Figure 31. Emissions results for CleanFleet Chevrolet delivery vans

Figure 32. Emissions results from the CleanFleet Ford delivery vans



Ethanol line-haul truck operated by Archer Daniels Midland in Illinois

early engines had not yet been developed for low oxides of nitrogen emissions and later compressed natural gas engines are showing oxides of nitrogen emission levels 50 percent to 75 percent less than comparable diesel engines.

The carbon monoxide emissions levels from the compressed natural gas trucks showed wide variability during the tests. The emissions levels ranged from 96 percent less to four-and-a-half times greater than from comparable diesel trucks. These compressed natural gas engines depend on correct functioning of the catalytic converter to achieve low carbon monoxide emissions; therefore, a malfunctioning converter results in very high emissions. Failure in this type of converter can be caused by incorrect air/fuel ratio in the engine. Cummins engineers have advised the program that these prototype engines are known to have a problem with air/fuel ratio drift, which probably explains the high levels of carbon monoxide being emitted by some of the trucks. Later certified versions of this engine are showing consistently low carbon monoxide emissions.

The hydrocarbon emission levels from the compressed natural gas trucks were about one to four times higher than those from comparable diesel trucks. The hydrocarbon emission levels measured were total hydrocarbons, including methane; therefore, higher levels are to be expected (natural gas is mostly methane). During certification emissions tests of later models of these engines, non-methane hydrocarbon levels were 70 percent less than those of an equivalent diesel engine.

Emissions Test Results from Ethanol Trucks

There is no industry standard test cycle for chassis dynamometer emission testing of heavy-duty trucks. The Central Business District cycle is generally used for testing transit buses and large trucks with automatic transmissions, but cannot be followed with manual transmission trucks. West Virginia University has used a modified Central Business District cycle, and, more recently, has developed and applied a new truck test cycle for our large trucks. Work is ongoing to define a truck test cycle (or cycles) that can be adopted as the industry standard.

As there is no standard cycle, and emission levels measured are very cycle dependent, the absolute emission levels measured are not particularly meaningful. Fortunately, however, the relative emission levels between alternative fuel trucks and diesel trucks are less dependent on the driving cycle. Therefore, we can make meaningful comparisons of the relative emission levels from alternative fuel vehicles and comparable diesel control vehicles.

We have studied the emissions data taken in fiscal year 1994 on 95 percent ethanol-fueled line-haul trucks in Illinois and 95 percent ethanol-fueled snowplows in Hennepin County, Minnesota. All these trucks use Detroit Diesel Corporation 6V92 engines. Particulate matter emissions from the ethanol trucks were quite low, averaging approximately 65 percent less than their diesel counterparts. Emissions of oxides of nitrogen were also lower, averaging about 25 percent less than the diesel trucks. In contrast, emissions of carbon monoxide and hydrocarbons from the alcohol trucks both averaged several times higher than comparable diesel trucks—about three times as high for carbon monoxide and five times as high for hydrocarbons.

The program has reviewed these unexpectedly high carbon monoxide and hydrocarbon emission measurements with Detroit Diesel Corporation engineers. The Detroit Diesel experts were surprised by the high carbon monoxide and hydrocarbon emissions findings because they are in sharp contrast to the engine emission certification results for this engine (see the Transit Bus section of this report for a discussion of the engine certification results). They noted that the carbon monoxide and hydrocarbon levels are high as the exhaust leaves the engine, but a catalytic converter is used, which brings these emissions down to very low levels. Therefore, an obvious explanation for the high carbon monoxide and hydrocarbon emissions is that the catalytic converters are not functioning properly in the field. Several factors could cause this malfunction, including failure of the converter itself, engine faults causing abnormal combustion (which could prevent the converter from functioning correctly), or failure of the converter to "light-off" sufficiently during the test driving cycles.

Whatever the explanation, the carbon monoxide and hydrocarbon emissions levels were disappointingly high when measured on test cycles believed to be fairly representative of in-city operation of large trucks.

Performance and Reliability

To track the performance and reliability of the test vehicles, personnel at all the sites record the details each time a vehicle undergoes maintenance or repair work. Extensive information is already available for the line-haul trucks operated by Archer Daniels Midland in Illinois.

Vehicle performance encompasses factors such as acceleration, hill climbing, driveability, and driver acceptance. Data on vehicle performance are collected in two ways: tests are conducted on parameters such as acceleration, and driver feedback is also recorded. The sidebar on page 48 highlights specific performance and reliability issues that have surfaced at each program site. As a direct result of this field experience,

Heavy-Duty Vehicle Performance and Reliability Issues

Project	Fuel	Performance	Reliability
Federal Express CleanFleet	85 percent methanol, compressed natural gas, liquefied petroleum gas, reformulated gasoline, electricity	Driveability and range complaints (separate reports available)	Original equipment manufacturer engines generally better than conversions
Acurex/VONS	Compressed natural gas	Hill-climb test slower than diesel; acceleration comparable to diesel	Numerous reliability problems indicate lack of development
New York City Sanitation	Compressed natural gas	Comparable performance; much quieter	One low-mileage piston failure
Illinois Energy and Natural Resources/ Archer Daniels Midland	95 percent ethanol	Comparable performance	Bearing failure caused by operator error[1]
Trucking Research Institute/ Hennepin County	95 percent ethanol	Performance complaints related to fuel pumps; also cold-starting problems	Fuel pump failures (under investigation)

[1] A new operator thought that the DDC-required fuel additive was an oil additive and added it to the crankcase. This diluted the oil and caused premature wear of the crankshaft bearings. Although this was a simple mistake, it does point to the necessity of thorough training for operators of alternative fuel vehicles.

Alternative Fuels in Action

During 3 years of operation, the four 95 percent ethanol line-haul trucks at Archer Daniels Midland in Illinois have accumulated more than 200,000 miles each. Maintenance and reliability have been comparable with diesels, demonstrating that ethanol is a viable choice of fuels for over-the-road trucking. Meanwhile, in Hennepin County, Minnesota, two ethanol-powered snowplows have plowed through extreme conditions. These snowplows, powered by Detroit Diesel 6V92 engines running on 95 percent ethanol, have endured the harshest winter in many decades, operating flawlessly in temperatures that dipped as low as 25 degrees below zero. During the summer, the trucks were use for road maintenance and operated reliably in extremely hot weather. The drivers' weekly reports compared the ethanol trucks quite favorably to their diesel counterparts.

the engine manufacturers involved in these projects have already made significant design improvements to their engines. For example, the Caterpillar 3406 engine demonstration in California has led to the development of a production version of the engine. As data on each engine type accumulate, the lessons learned from these projects will further advance the development of heavy-duty alternative fuel engines.

The repairs on the Illinois line-haul trucks running on 95 percent ethanol and diesel are summarized in Figure 33. There has been little difference in the number or type of repairs done on the ethanol and on the diesel trucks at this site.

Fuel Economy

Each time a truck is refueled, the driver records the quantity of fuel put into the truck and its odometer reading. From these records, the actual in-use fuel economy of the vehicle can be calculated. In addition, when the vehicle is tested for emissions on the transportable chassis dynamometer, the fuel economy is also measured.

The in-use fuel economy varies from refueling to refueling because of factors such as variations in driving styles and day-to-day duties. The data from the chassis dynamometer, on the other hand, are taken under tightly controlled conditions and therefore vary little. The disadvantage of the dynamometer tests is that the driving cycle used during the tests may not be representative of the vehicle's normal operation.

Figure 34 presents the large truck fuel economy data available to date. In some of the sites, only in-use results are available. All the results are presented on a mile per diesel equivalent gallon basis.

For the Illinois line-haul trucks, the fuel economy measured with the chassis dynamometer is lower than the in-use figures. This probably results from the difference between the dynamometer driving cycle and the actual driving cycle. The West Virginia University Truck Cycle, which emulates city driving, was used on the dynamometer; however, the line-haul trucks typically drive long distances on the highway. For the New York City refuse packers, which operate primarily on a stop-and-go driving cycle, the dynamometer results (using the standard Central Business District driving cycle) fall within the range of in-use results for the compressed natural gas trucks and close to the range of in-use results for the diesel trucks.

Most of the alternative fuel vehicles demonstrated fuel economies comparable to their diesel counterparts. However, the fuel economy of the compressed natural gas line-haul truck in California (with a Caterpillar 3406 engine) was significantly lower than that of its diesel counterpart. This may be attributed to factors such as pumping losses (throttled engine), lack of fuel system development, unnecessary operation of cooling fan, and exhaust back pressure. (These vehicles were later retrofitted with dual exhausts to lower exhaust back pressure.)

Significant quantities of data have been accumulated for the commercial delivery vans in the Federal Express CleanFleet project. Figure 35 presents a summary of the in-use and chassis dynamometer fuel economies on a mile per gasoline equivalent gallon basis. In general, all the chassis dynamometer results show higher fuel economies than the in-use figures. This probably results from the driving cycle of the urban delivery vans. The vans spent more stopping and idling time in use than is included in the Federal Test Procedure driving cycle used in the dynamometer tests.

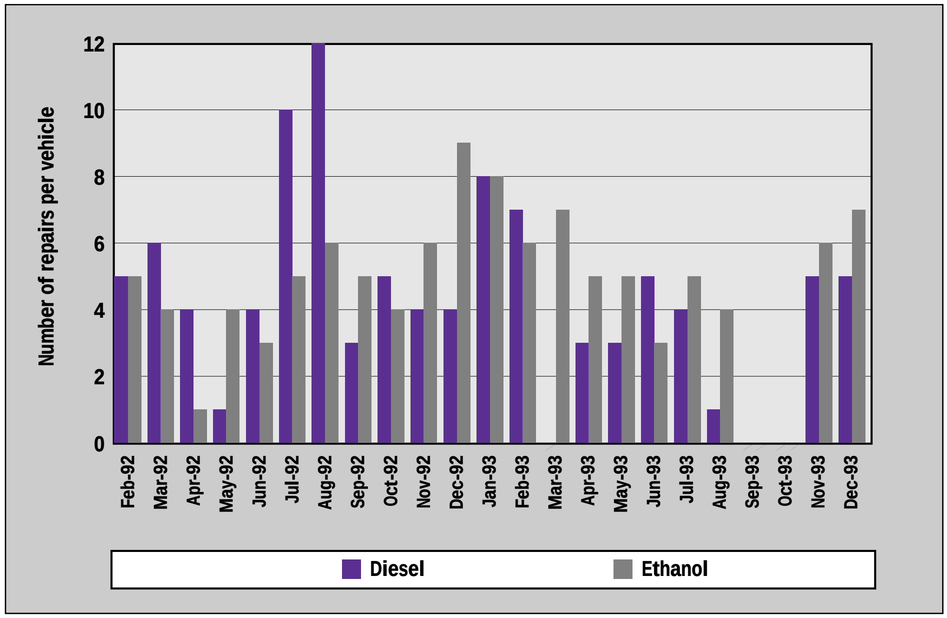
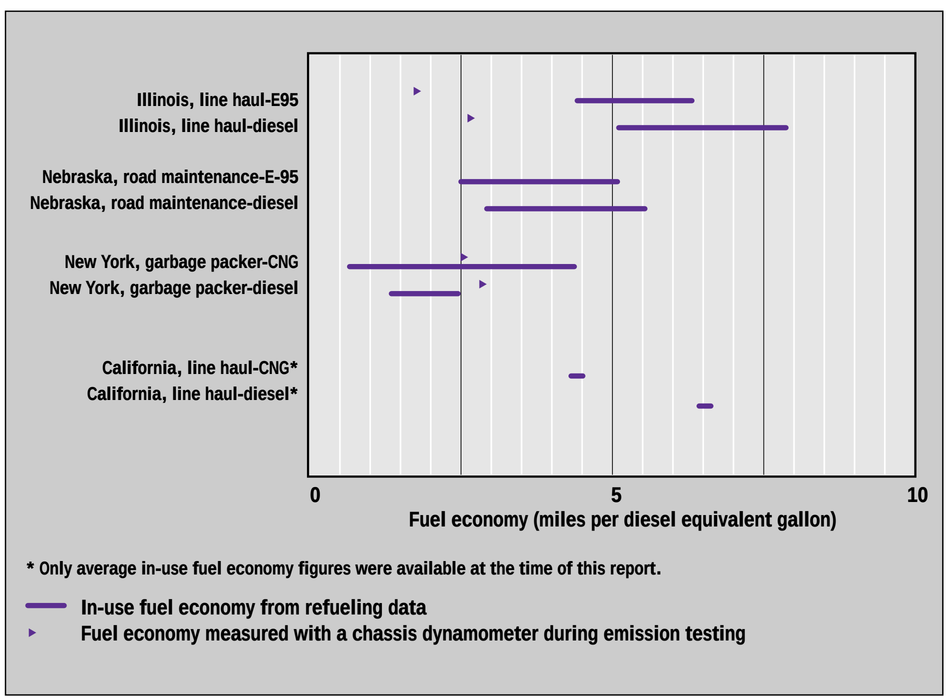


Figure 33. Number of repairs done each month on 95 percent ethanol and diesel line-haul trucks

Figure 34. Large truck fuel economy



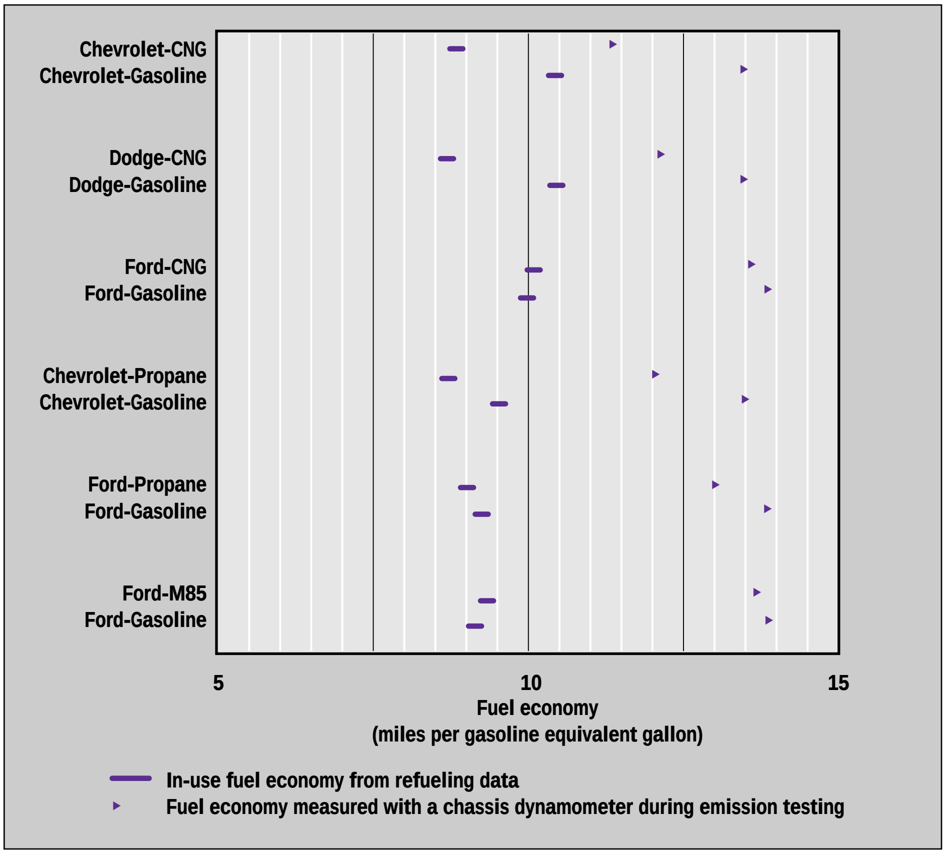


Figure 35. CleanFleet fuel economy results

The Chevrolet propane and compressed natural gas and Dodge compressed natural gas vehicles show about 10 percent to 15 percent lower in-use fuel economy than the control gasoline vehicles. The dynamometer results mirror this difference. All the Ford vehicles, which are operating on compressed natural gas, propane, and 85 percent methanol, have fuel economies within a few percent of their gasoline counterparts in both the in-use and dynamometer data.

With all engine manufacturers working on increasing efficiency and reducing emissions, fuel economy is expected to improve for alternative fuel and conventional fuel heavy-duty engines. The manufacturers' efforts have already paid off handsomely—for example, line-haul trucks have exhibited a 40 percent to 50 percent improvement in fuel economy in the past 10 years. These improvements have come from advances in electronic engine controls, as well as vehicle design and aerodynamics. For alternative fuels, most engine companies are in the early stages of the development curve. Therefore, there may be considerable room for further improvement.

Cost

Keeping operating costs low is critical to successful heavy-duty vehicle operations. For example, the American Trucking Association reports that in line-haul trucking, the profit margin is very tight—on the order of 2 percent. This means that any increase in operating cost either makes the operation unprofitable or must be passed on to the consumer.

Acquisition Costs

The additional acquisition costs for the large alternative fuel trucks are similar to those of the buses, as described in the previous section. Many of the engines are exactly the same engines as those used in the transit buses.

The Federal Express CleanFleet and United Parcel Service Fleet vehicles have engines similar to those of the light-duty trucks, so their acquisition costs are similar to those of the light-duty trucks.

Fuel Costs

Although alternative fuels enjoy tax breaks in many states, high production costs for some alternative fuels may offset the breaks. Figure 36 shows fuel cost per diesel equivalent gallon paid by the large truck operators. The fuel cost per mile traveled also depends upon the fuel economy of each vehicle.

Maintenance Costs

In virtually all the current heavy-duty alternative fuel projects, alternative fuel vehicles have cost more to maintain. A probable cause is the lack of development of the alternative fuel engines and fuel systems. As alternative fuel engines attain higher mileage levels, and manufacturers refine engine and fuel system designs based on the experience gained in this program, reliability levels comparable to diesel engines may result. The current generation of diesel engines has achieved a high level of reliability and longevity. Engine manufacturers have reported cases of diesel engines running more than 1 million miles without an overhaul. Alternative fuel engines will have to log many more miles before their longevity can be evaluated fairly.

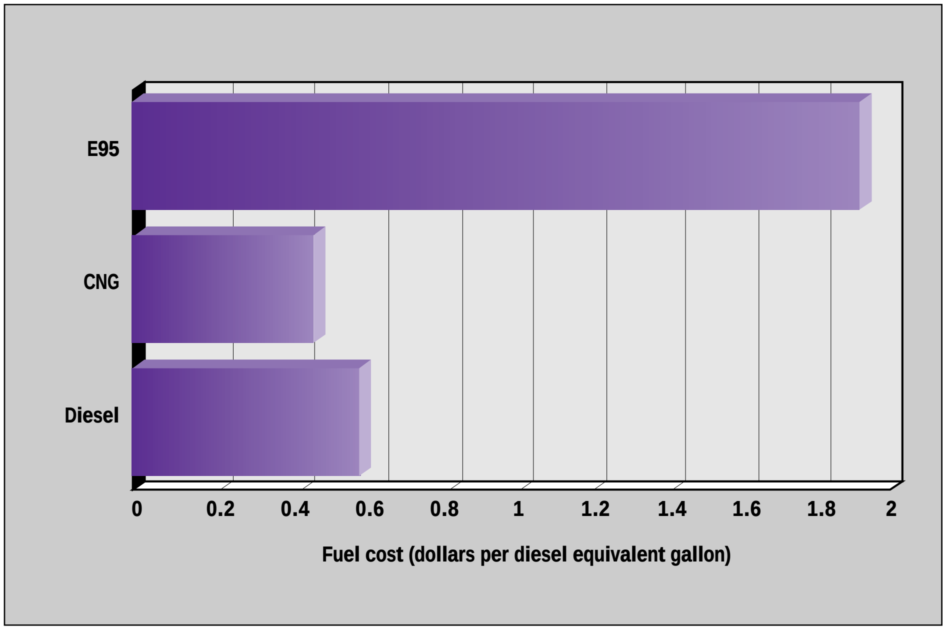


Figure 36. Fuel cost per diesel equivalent gallon

United Parcel Service Expands its Compressed Natural Gas Fleet

Based on the excellent performance of the 20 dedicated compressed natural gas engines in their Washington, D.C., fleet, United Parcel Service has decided to order 276 more of the Tecogen 4.3L compressed natural gas engines and retrofit additional vehicles with these engines. The repowered vehicles will operate in Connecticut and Southern California. United Parcel Service expects compressed natural gas vehicles to play an important part in its fleet operations in the future.

Safety

Safety Incidents

In general, the test fleet has a very good safety record. Safety incidents involving the alternative fuel systems have been rare. However, two sets of incidents did occur: one with compressed natural gas cylinders and the other with methanol cold-start injectors. The program has investigated the causes of these incidents and has taken steps to prevent their recurrence.

During the past year, there were two serious incidents involving Chevrolet C-2500 dedicated compressed natural gas pickup trucks, but these trucks were not part of the General Services Administration's fleet. Minnegasco and Pacific Gas and Electric Company owned and operated the two vehicles. (The General Services Administration had 600 of the same model of vehicle in service.) The high-pressure fuel tanks failed on both vehicles. The equipment was lost, but no one was seriously injured.

Production Automotive Systems, Inc., converted the two pickup trucks for General Motors. The fuel tanks, manufactured by Comdyne, Inc., were fully wrapped aluminum-lined cylinders with an E-glass/epoxy overwrap. Stress corrosion cracking of the overwrap developed as a result of exposure to acids, which caused the cylinders to rupture during refueling. The Gas Research Institute sponsored an investigation, which was conducted by Southwest Research Institute. The investigators recommended:

- Modifying the design of the stone shield to prevent immersion of the cylinder in trapped liquids.
- Improving cylinder design by using coatings with proven acid resistance.
- Training operators of existing natural gas vehicles to increase awareness of the effects of acids on uncoated, composite-wound cylinders.

The Gas Research Institute also recommended that all natural gas vehicle owners immediately inspect cylinders for stress corrosion cracking, that cylinders be inspected periodically, and that owners be cautioned not to expose these cylinders to acids. The Gas Research Institute is distributing safety guidelines on natural gas vehicles. The Chevrolet C-2500 natural gas pickup trucks are no longer being sold.

Inspectors found damage on two of the compressed natural gas fuel tanks on the line-haul trucks in California. One was damaged by a leaking exhaust system and could not be repaired; the hot exhaust gases had burned an area of the composite wrap material on the outside of the tank. The tank did not rupture. When the damage was discovered, the tank was replaced. The other damaged tank showed a gouge. The tank was repaired and the vehicle was returned to service.

The National Renewable Energy Laboratory funded an inspection and study of compressed natural gas fuel tanks on school buses sponsored by the Department of Energy. Inspectors checked 118 gas cylinders and tagged 4 damaged cylinders. The damaged cylinders were shut off from the rest of the bus fuel system and their pressure was reduced until the cylinders could be recertified or replaced. A full report of the inspection results is available from the National Renewable Energy Laboratory.

The Federal Express CleanFleet had two fires on methanol-powered Ford vans. One vehicle was repaired; the other was a total loss. No one was injured. Both fires were attributed to fuel leaks at the cold-start injector. Since the vehicles were built, Ford has determined that this component is not needed, and it has been removed from the remaining vehicles.

Infrastructure Support

To meet the demands that the increasing numbers of alternative fuel vehicles place on the U.S. marketplace, an associated infrastructure has developed. This infrastructure, consisting of refueling sites and maintenance and storage facilities, is the fabric that holds together the components of the alternative fuel industry. The infrastructure's growth has been stimulated by various incentives such as the Alternative Motor Fuels Act of 1988, the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, and Executive Order 12844 (*Federal Use of Alternative Fueled Vehicles*, April 1993).

Refueling Sites

Light-Duty Vehicles

Figure 37 illustrates the recent rapid growth of compressed natural gas, 85 percent methanol, and 85 percent ethanol refueling stations. The total number of these refueling sites has quadrupled in the past 4 years. More than 90 stations offer 85 percent methanol and about 30 offer 85 percent ethanol. The number of compressed natural gas sites has more than tripled since 1990, growing from 300 to more than 1,000. About three-fifths of the compressed natural gas sites are fully available to the public or may be made available by arrangement, usually with the local utility company. As shown in Figure 38, these sites are distributed throughout the United States. The 3,300 liquefied petroleum gas sites in the figure represent responses to a 1992 survey by the National Propane Gas Association. However, the Liquefied Petroleum Gas Clean Fuels Coalition estimates that there are now as many as 11,000 sites where liquefied petroleum gas can be obtained for use as a motor fuel.

Buses and Heavy-Duty Vehicles

In general, transit bus agencies and heavy-duty fleets install their own fueling stations and do not use public fueling stations. The refueling station for each alternative fuel poses unique challenges both in terms of set-up costs and safety considerations.

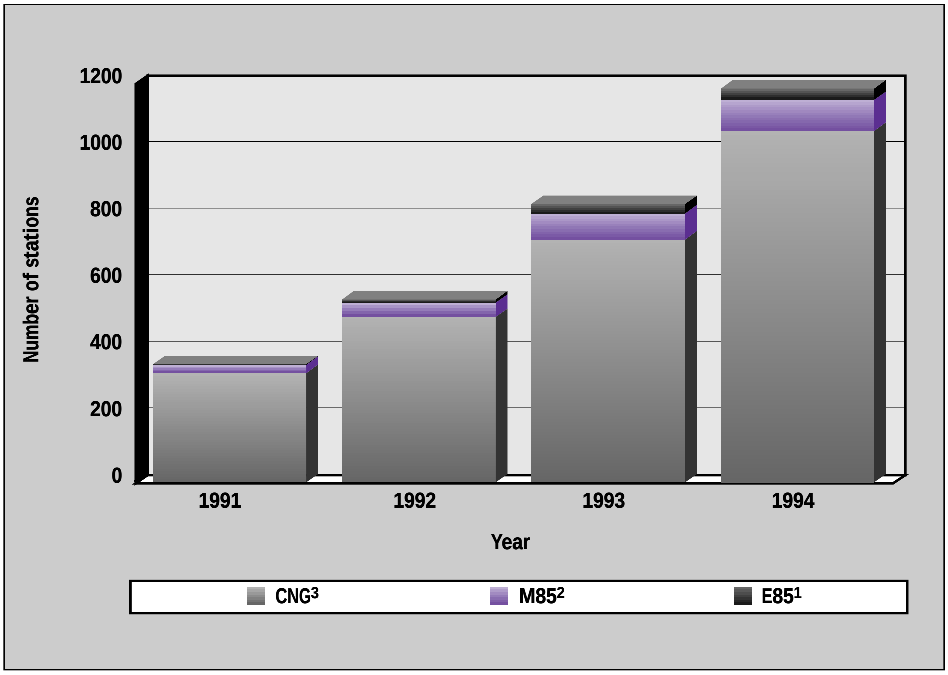


Figure 37. Estimated number of refueling stations by year and fuel type

Sources:

[1] National Corn Growers Association

[2] Various state energy offices and the Department of Energy

[3] American Gas Association

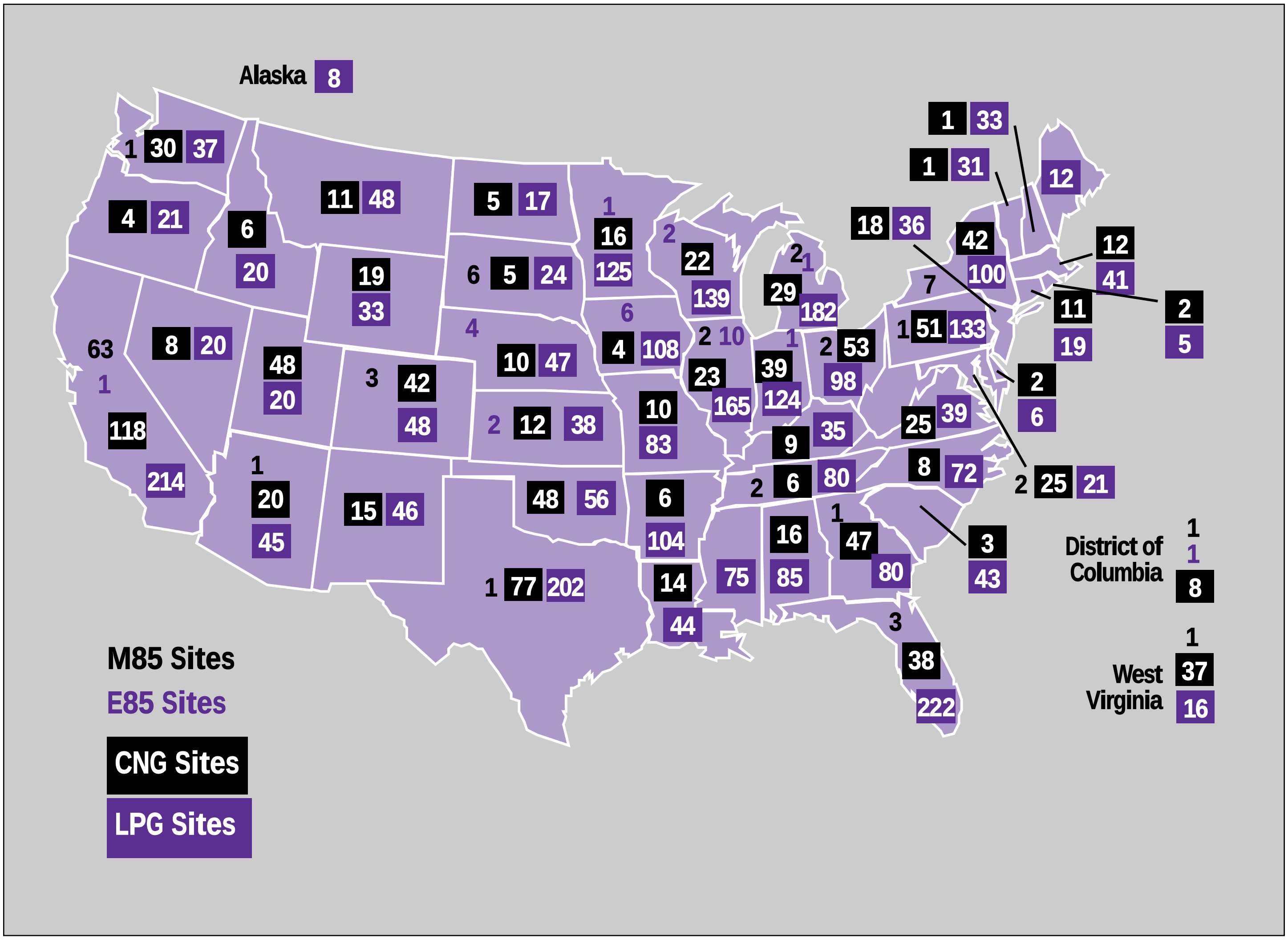


Figure 38. Alternative fuel refueling sites in each state

For methanol and ethanol refueling stations, it is relatively easy to install a new in-ground or above-ground fuel storage tank. However, because the alcohol fuels have corrosive properties, special attention must be given to the choice of materials used to make the tank and pump. For the compressed natural gas refueling infrastructure, various choices exist. All options tend to be more expensive than the alcohol fuels. A slow-fill system uses a small compressor and has the lowest cost. In a slow-fill system, the vehicles are hooked up to a refueling hose overnight. Typical refueling time is about 8 hours. At the other end of the spectrum, a fast-fill system requires a large and expensive compressor station. These can typically refill a vehicle with compressed natural gas in about the same amount of time it takes to refill with diesel or gasoline. Most public access compressed natural gas stations are fast fill. These stations can cost $200,000 to $300,000 to build.

A persistent problem with the installation of alternative fuel refueling stations is the lack of consistent zoning and safety requirements. Each municipality has its own unique requirements. This prevents the standardization of equipment and installation procedures, which in turn leads to higher costs.

Maintenance Facilities

Light-Duty Vehicles

Original equipment manufacturer dealerships perform maintenance on light-duty alternative fuel vehicles in the test fleet. Dealership personnel have been factory trained to service the type of alternative fuel vehicles the particular dealership carries. They are particularly knowledgeable about the vehicle's fuel system and electronics. The General Services Administration reports that vehicle maintenance was sometimes difficult in the early years of the program (1991-1992), but that it generally no longer presents a problem. The dealerships now provide reasonable service for the vehicles they sell. Converted vehicles can be returned to the conversion shop for service.

To expand the pool of qualified technicians to service alternative fuel vehicles that have been converted to compressed natural gas or liquefied petroleum gas, the Department of Energy's Office of Transportation Technologies, in compliance with Section 411 of the Energy Policy Act of 1992, has funded a national program to certify training programs for technicians who convert vehicles to alternative fuels, and who maintain and repair the vehicles and refueling stations. This program is called CHAMP (Certification of Higher-learning in the Alternative Motor Fuels Program). The CHAMP team is composed of 16 charter organizations that represent automotive vehicle manufacturing, education and certification, alternative fuels production, vehicle conversions, automotive service, and the public. This team will provide the guidance and resources to aid the certification program's development, implementation, and evaluation.

Transit Buses and Heavy-Duty Vehicles

Generally, the transit agency or the engine dealership performs maintenance on the alternative fuel buses in the program. Because transit agencies usually have only one or two central sites for maintaining their entire fleet, these sites are outfitted for the alternative fuels used by the agency and the technicians at those sites gain experience with the alternative fuel systems quickly. In contrast, there are often only a few alternative fuel heavy-duty vehicles at any given site. The lack of trained maintenance technicians with experience in alternative fuel technologies has been a problem at these sites. In addition, many of the maintenance shops used by the heavy-duty vehicles do not have adequate ventilation and gas detectors to safely work on gaseous fuel vehicles indoors. Although both situations are improving, progress is slow. A maintenance facility may not be able to justify upgrading equipment and training its personnel to maintain alternative fuel vehicles that often number less than ten in a given site.

Vehicle Storage

Special precautions must be taken before storing gaseous fuel vehicles indoors. Indoor storage requires gas detectors and adequate ventilation systems. Many underground parking facilities do not currently permit compressed natural gas or liquefied petroleum gas vehicles. This presents a problem for pickup and delivery vehicles operating in urban areas. In the long term, this issue will need to be resolved if compressed natural gas and liquefied petroleum gas are to gain widespread use for this type of service.

Where We Are

The infrastructure for light-duty alternative fuel vehicles appears to be growing in pace with the number of vehicles of this type being introduced. No significant impediment to further expansion is evident. The infrastructure for transit buses is also developing along with the vehicles. However, there have been significant infrastructure problems with alternative fuel use in large trucks. Virtually every large truck project has encountered problems with some aspect of refueling, maintenance, or storage. Continued government support of heavy-duty projects will increase familiarity with the infrastructure issues associated with these vehicles and help drive the private sector to resolve these issues.

Vehicle Availability

Alternative Fuel Vehicles in Use

Figures 39 through 41 give some perspective on the number of Federal and non-Federal light-duty alternative fuel vehicles in the United States for the past 3 years. The figures also present predictions on the number of alternative fuel vehicles that will be in operation in 1995. The Department of Energy's Energy Information Administration estimated these numbers using the best sources available. The number of liquefied petroleum gas vehicles is difficult to estimate because they are almost all conversions. Current estimates put the number of liquefied petroleum gas vehicles in operation in the United States at approximately 186,000.

In February 1994, the American Public Transit Association conducted a survey of transit bus agencies. The alternative fuel share of the U.S. bus market at that time was about 2 percent of the approximately 50,000 buses on the road. The market penetration of alternative fuels in the bus sector is substantially ahead of any other transportation sector. A transit bus is an ideal application for alternative fuels because the buses are centrally refueled (requiring less infrastructure development), and extra space for larger fuel tanks is generally available on a bus.

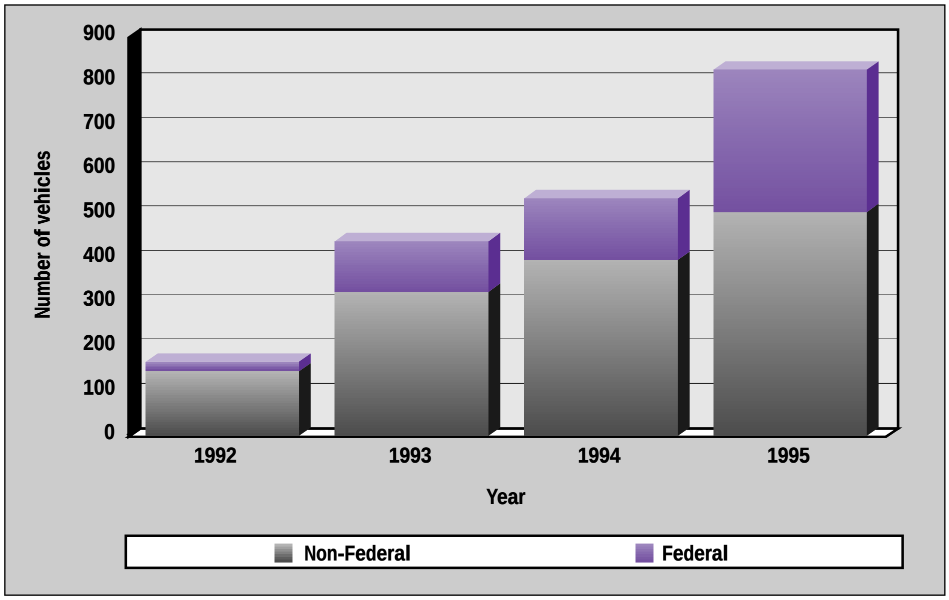
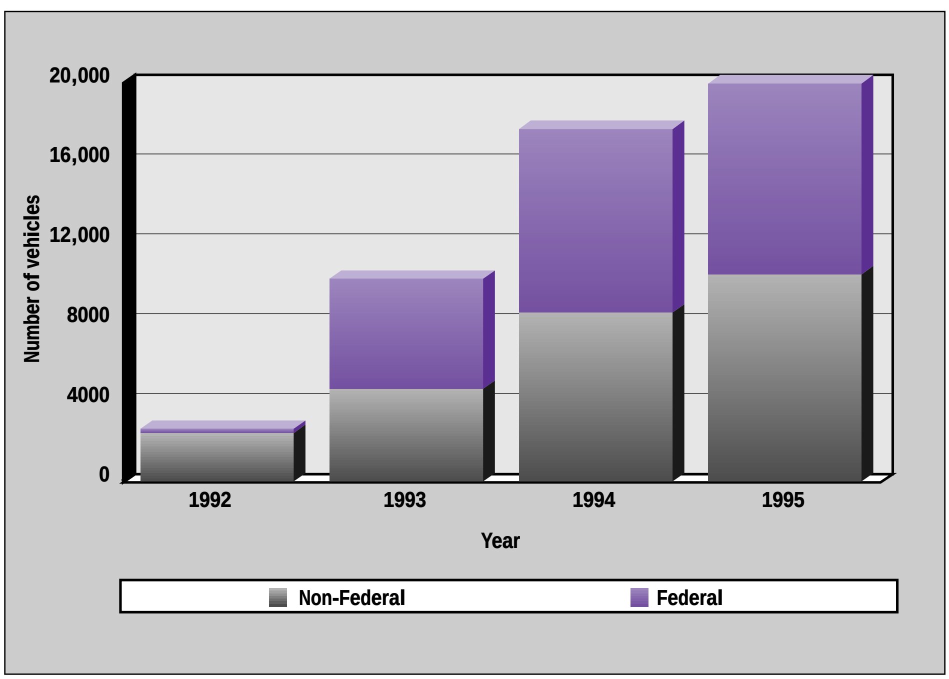


Figure 39. Number of E85 vehicles in U.S. fleets

Figure 40. Number of M85 vehicles in U.S. fleets



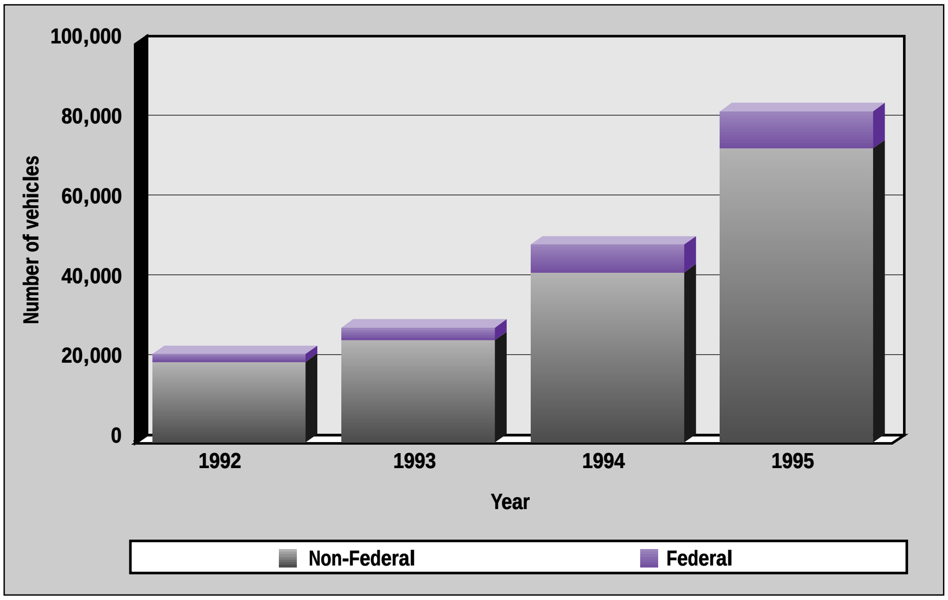


Figure 41. Number of CNG vehicles in U.S. fleets

Vehicle Availability

The sidebar on page 61 lists the types of vehicles that were available from the original equipment manufacturers in 1994 and those that are planned for production in 1995. The models offered in 1994 included three compressed natural gas models, four 85 percent methanol flexible-fuel models, and one heavy-duty liquefied petroleum gas truck. Models to be offered in 1995 include two flexible-fuel 85 percent methanol vehicles, four dedicated compressed natural gas models, two bi-fuel compressed natural gas models, and one liquefied petroleum gas heavy-duty truck.

The General Services Administration has indicated that original equipment manufacturer offerings in calendar year 1995 may not be sufficient to meet the purchase requirements of the Energy Policy Act of 1992 and Executive Order 12844. These mandates require the purchase of 15,000 alternative fuel vehicles for the Federal fleet in 1995. They plan to supplement original equipment manufacturer orders with purchases made through qualified vehicle converters. A qualified vehicle converter is an original equipment manufacturer-approved organization that converts standard vehicles to run on an alternative fuel.

In some cases, the supply of compressed natural gas vehicles offered for purchase in calendar year 1995 may be delayed because of cylinder supply problems.

Alternative fuel vehicles offered by U.S. original equipment manufacturers

1994 Model Year Vehicles

Manufacturer	Model	Body Style	Design Fuel	Secondary Fuel
Chrysler - Dodge	RAM van/wagon	Full-size van	Compressed natural gas	
Chrysler - Dodge	Spirit	Compact sedan	85 percent methanol	Gasoline
Chrysler - Dodge	Caravan	Minivan	Compressed natural gas	
Chrysler - Dodge	Intrepid	Mid-size sedan	85 percent methanol	Gasoline
Chrysler - Plymouth	Acclaim	Compact sedan	85 percent methanol	Gasoline
Chrysler - Plymouth	Voyager	Minivan	Compressed natural gas	
Ford	Taurus	Mid-size sedan	85 percent methanol	Gasoline
Ford	F600/700	Heavy-duty truck	Liquefied petroleum gas	

1995 Model Year Vehicles

Manufacturer	Model	Body Style	Design Fuel	Secondary Fuel
Chrysler - Dodge	Intrepid	Mid-size sedan	85 percent methanol	Gasoline
Chrysler - Dodge	Ram Van/Wagon	Full-size van	Compressed natural gas	
Chrysler - Dodge	Ram pickup	Full-size pickup	Compressed natural gas	
Chrysler - Dodge	Caravan	Minivan	Compressed natural gas	
Chrysler - Dodge	Dakota	Mid-size pickup	Compressed natural gas	
Chrysler - Plymouth	Voyager	Minivan	Compressed natural gas	
Ford	Taurus	Mid-size sedan	85 percent methanol	Gasoline
Ford	F150/250	Full-size pickup	Compressed natural gas	Gasoline
Ford	Econoline	Full-size van	Compressed natural gas	Gasoline
Ford	F600/700	Heavy-duty truck	Liquefied petroleum gas	

Information Dissemination

Information dissemination is an important component of the Department of Energy's program. Accurate, timely, and readily available information can only help to hasten public acceptance and the enthusiastic adoption of alternative fuel vehicles. Programs to provide information about alternative fuels are mandated by the same Federal legislation that affects other alternative fuels arenas: the Alternative Motor Fuels Act of 1988, the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, and Executive Order 12844.

The Alternative Fuels Data Center

To make the best possible use of the information being collected through the various programs, the Department's Office of Transportation Technologies' Office of Alternative Fuels established the data center (AFDC) at the National Renewable Energy Laboratory. The center serves as the focal point for data generated by all the test fleets. The center maintains information on line in computerized data bases. Hard copies are available as well, and are distributed by personnel manning the National Alternative Fuels Hotline (1-800-423-1DOE).

The center's engineers validate the quality of the data they receive through various computerized, statistical, and manual procedures. If the data meet these quality tests, they are loaded into the production data base. If the data do not meet the quality standards, they are investigated to determine the error for possible correction of the data and/or to implement procedures to prevent similar errors in future data. Once loaded into the data base, the data are analyzed and reports are developed. All information in the data base is made available to other researchers, private industry, and anyone else interested in the information. Access is provided electronically via dial-up modem or through the international computer network, Internet.

The Alternative Fuels Data Center, where all data from the program are collected, analyzed, and disseminated.

Several methods of access are available. AFDC/View and AFDC/Menu are two systems developed by the data center's engineers to allow users quick and easy access to more than 300 predetermined queries. Users generally specify vehicle models or locations of interest and the system returns raw and summary data. In addition to these methods, the center also provides access via systems that allow the users to program their own queries. These methods are recommended for the serious researcher, not the casual user. Another method of accessing the data on Internet is via the World Wide Web (WWW), using browsers such as Mosaic. Because this graphical user interface is very intuitive and user friendly, it is gaining wide popularity. The White House has just announced that it has information available on Internet via the World Wide Web. The World Wide Web does not limit access to raw data but also can include complete reports, graphics, photographs, sound, and even movies. The center currently maintains maps of alternative fuel refueling sites, a data base of biofuels literature, and the complete text of the center's quarterly newsletter. This access method will be greatly expanded in the coming year to include Department of Energy alternative fuels reports and most program summary information.

The hotline staff maintains a large inventory of information of interest to the public as well as government workers and researchers on alternative fuels and the supporting industries. Everyone is welcome to call and have questions answered by an informative operator. The hotline operators have immediate access to the center's data bases, along with information that has not yet been put into the data base. They can answer questions immediately, mail any requested information, or provide reference to other sources of information.

The center is constantly producing and updating a series of publications. This year several brochures were published, some of which covered contacts in the alternative fuels industry, facts about Federal legislation, facts about compressed natural gas conversions, and maps of refueling site locations. In addition, the center publishes a quarterly newsletter that currently has a circulation of nearly 15,000 and is also available electronically.

Data center personnel are aggressively pursuing establishing a comprehensive data base of research and demonstration information on alternative fuels. Materials that are not copyrighted will be available as complete documents. Copyrighted information will be maintained as a literature citation. The hotline will use this system. In addition, a new interface is being developed to guide on-line users through the maze of information and point them to the information they need. A prototype version of this system will be available in 1995.

Market Research

In 1994, a subcontractor conducted market research to obtain independent feedback on the types of information needed by prospective and current users. The research consisted of interviews with existing and potential customers. It netted positive feedback, finding that the current hotline and data center service is meeting expectations and that the potential to convert hotline users to data center users is high. Most respondents were interested in light-duty vehicle data, and the greatest interest appeared to be in compressed natural gas as a fuel. The research determined that needs cannot be met with one presentation format; a broad mix of styles is needed. The current approach to information dissemination, as well as future plans, tracks closely with these findings.

Appendix

Table A-1: Federal Agencies Participating in the Light-Duty Vehicle Program

Argonne National Laboratory	Federal Emergency Management Agency
Bureau of Indian Affairs	Federal Energy Regulatory Agency
Central Intelligence Agency	Federal Aviation Administration
Colorado Army National Guard	Federal Energy Regulatory Commission
Consumer Product Safety Commission	Federal Highway Administration
Department of Agriculture	Government Printing Office
Department of the Air Force	Herbert Hoover National Historic Site
Department of the Army	Library of Congress
Department of Commerce	NASA Transportation Section
Department of Defense	National Archives and Records Administration
Department of Energy	National Credit Union Administration
Department of Health and Human Services	National Guard Office
Department of the Interior	National Park Service
Department of Justice	National Renewable Energy Laboratory
Department of Labor	Naval Petroleum Reserve
Department of State	Office of Surface Mining
Department of Transportation	Small Business Administration
Department of the Treasury	South Dakota Urban Indian Health
Department of Veterans Affairs	U.S. Bureau of Alcohol, Tobacco & Firearms
Environmental Protection Agency	U.S. District Court
Federal Drug Administration	U.S. Geological Survey

Table A-2: Status of the Current Light-Duty Test Fleet

Vehicle Description	Model Year	Fuel	Design	Number Type	Reported Number of Miles
Dodge Ram Van	1992	CNG	Dedicated	63	598,290
Dodge Ram Van	1994	CNG	Dedicated	12	21,612
Dodge Spirit	1994	M85	Flexible	222	1,282,247
Chevrolet C-2500 Pickup	1992	CNG	Dedicated	145[1]	407,492
Chevrolet Lumina	1991	M85	Flexible	25[1]	666,729
Chevrolet Lumina	1993	M85	Flexible	21	104,500
Chevrolet Lumina	1992	E85	Flexible	32	213,552
Ford Taurus	1991	M85	Flexible	39[1]	955,021
Ford Taurus	1993	M85	Flexible	17	96,072
Ford Taurus	1994	E85	Flexible	13	9,208
Ford Econoline Van	1992	M85	Flexible	14	66,933
Total AF Vehicles	All			603	4,421,656
Total Control Vehicles	All	Gasoline		243[2]	1,820,752
Total AF and Control	All			846	6,242,408

[1] Removed from data collection in 1994 (except five 1991 Chevrolet Luminas)

[2] Ninety-one control vehicles (all 1991 Tauruses, 1991 Luminas, and 1993 C-2500 pickups) were removed from data collection in 1994

Table A-3: Emissions Tests Completed on Light-Duty Vehicles in 1994

Vehicle Model	Model Type	Year	Number of Vehicles	Number of Tests
Chevrolet C-2500 Pickup	1992	CNG	5	5
Chevrolet C-2500 Pickup	1992	Standard	2	2
Chevrolet Lumina	1992	E85 flexible-fuel	13	54
Chevrolet Lumina	1992	Standard	14	19
Dodge B-250 Van	1992	CNG	11	16
Dodge B-250 Van	1992	Standard	9	14
Dodge Spirit	1993	M85 flexible-fuel	44	172
Dodge Spirit	1993	Standard	43	61
Ford Econoline Van	1993	M85 flexible-fuel	2	12
Ford Econoline Van	1993	Standard	3	6
Total			146	361

Table A-4: Fuel System Parts Replacements on Light-Duty Vehicles

Vehicle Model	Fuel	Number of Vehicles	Total Fuel-Related Repairs
1991 Ford Taurus	M85	38	55 fuel pumps 47 processors 29 fuel injectors 30 methanol wiring harnesses 11 fuel pressure regulators 10 fuel tanks 13 mass air flow sensors 21 fuel sending units
	Gasoline	9	No fuel-related parts replaced
1991 Chevrolet Lumina	M85	33	16 fuel injectors 7 fuel pump speed controllers 2 fuel pumps
	Gasoline	8	1 open circuit to oxy. sensor 1 evap. solenoid/sensor 1 oxygen sensor 1 intake manifold gasket
1992 Dodge Ram Van	CNG	42	4 oxygen sensors 3 fuel pressure sensors 2 speed sensors 11 sets of fuel injectors 7 check valves 4 fill valves
	Gasoline	0	
1993 Dodge Spirit	M85	54	3 fuel flow sensors 3 flexible-fuel sensors 1 fuel pump
	Gasoline	3	1 fuel sending unit

Table A-5: Summary of the Alternative Fuel Transit Buses in the Data Collection Program

Site	Fuel	Number of Alternative Fuel Buses	Months of Data	Total Mileage on Alternative Fuel Buses
Houston	LNG/diesel dual-fuel	10	17	376,000
Miami	CNG	5	12	66,000
Tacoma	CNG	5	7	141,000
Peoria	E95/E93*	5	21	357,000
Minneapolis	E95	5	3	24,000
Miami	M100	5	12	134,000
New York	M100	5	0	0
St. Louis	Biodiesel (B20)	5	4	75,000

* Peoria switched from E95 to E93 in March 1994 for financial reasons. Approximately 75 percent of the above mileage had been accumulated when this switch was made.

Table A-6: Summary of the Heavy-Duty Vehicles in the Data Collection Program

Project	Fuel	Engines	Vocation	Number of Vehicles/Controls	Sponsors	Launched
Federal Express CleanFleet	M85 CNG Propane RFG		Local delivery	84/27	NREL, SCAQMD, CEC, Federal Express, OEMs, Fuel suppliers	10/92
Trucking Research Institute/United Parcel Service	CNG	Tecogen 4.3 L	Local delivery	20/5	NREL, UPS	09/94
Acurex/VONS Grocery Company	CNG	Caterpillar 3406	Line haul	1/1	NREL, SCAQMD, SoCal Gas, CEC	10/92
New York City Department of Sanitation	CNG	Cummins L10	Garbage packer	6/3	NREL, NYC Department of Sanitation	11/92
Illinois Energy and Natural Resources/ Archer Daniels Midland	E95	DDC 6V92	Line haul	4/1	NREL, Illinois ENR	10/92
Trucking Research Institute/Hennepin County, Minnesota	E95	DDC 6V92	Dump truck/ snowplow	2/1	NREL, Hennepin County	10/93
Trucking Research Institute/Nebraska	E95	DDC 6V92	Dump truck/ snowplow	2/0	NREL, Nebraska	09/94
Trucking Research Institute/Acurex	CNG	DDC Series 60	City delivery	1/1	NREL, SCAQMD, SoCal, Gas, CEC	09/94
Trucking Research Institute/Ag Products	Biodiesel	DDC, Cummins, Mack	Line haul	6/3	NREL, Ag Products	10/94

Table A-7: Vehicles in the Heavy-Duty Grant Program: Phase 0 and 1 School Bus Grants

Phase	Operating Jurisdiction	State	Number	Fuel	Vehicle Type
0	Tulsa County	Oklahoma	55	CNG	School buses
0	Tulsa County	Oklahoma	45	CNG	School buses[1]
0	Town of Weston	Massachusetts	3	CNG	School buses
0	Town of Weston	Massachusetts	2	CNG	School buses[1]
0	Wood County	West Virginia	2	CNG	School buses
0	Wood County	West Virginia	2	CNG	School buses
0	Wood County	West Virginia	4	CNG	School buses[1]
1	Maricopa County	Arizona	4	CNG	School buses
1	Braxton County	West Virginia	3	CNG	School buses
1	Montgomery County	Pennsylvania	1	Methanol	School bus
1	D.C. Public Schools	District of Columbia	4	CNG	School buses
1	Springfield School District	Missouri	4	CNG	School buses
1	Jordan School District	Utah	4	CNG	School buses
1	University of Vermont	Vermont	2	CNG	School buses
1	Shenendehowa School District	New York	2	CNG	School buses
1	Marcus Whitman School District	New York	2	CNG	School buses
1	Albuquerque	New Mexico	4	CNG	School buses
1	Franklin County	Kentucky	4	CNG	School buses
1	Montgomery County	Maryland	3[2]	CNG	School buses
1	Baltimore County	Maryland	3[2]	CNG	School buses
	Total		153		

[1] Conversion vehicles (all others are OEM vehicles)

[2] Two of the vehicles were purchased with DOE funding; one was purchased with Maryland state funds.

Table A-8: Vehicles in the Heavy-Duty Grant Program: Phase 2 School Bus and Heavy-Duty Vehicle Grants

Phase	Operating Jurisdiction	State	Number	Fuel	Vehicle Type
2	Peoria	Illinois	2	E95	Snowplow/construction trucks
2	Peoria	Illinois	1	E95	School bus
2	Louisville/ Jefferson County	Kentucky	3	CNG	Municipal wreckers
2	Mecklenburg County	North Carolina	4	CNG	School buses
2	State of Nevada	Nevada	2	CNG	15,000-GVW Crew Cab dump trucks
2	State of Nevada	Nevada	2	CNG	Tymco street sweepers
2	New York City	New York	2	CNG	Athey street sweepers
2	Bethlehem School District, Albany County	New York	2	CNG	Transit-style buses used in school bus operation
2	East Providence	Rhode Island	4	CNG	School buses
2	Richland and Lexington Counties	South Carolina	4	CNG	Heavy-duty trucks
2	Richmond, Northern Virginia, and Suffolk	Virginia	3	LPG	Class 7 (28,000-33,000 GVW) dump trucks
2	Virginia Beach	Virginia	1	CNG	School bus
2	Pleasants County	West Virginia	2	CNG	Transit-style buses used in school bus operation
2	Washington, D.C.	District of Columbia	3	CNG	Jet Vac machines
2	Washington, D.C.	District of Columbia	1	CNG	38,000-GVW dump truck
2	Waco and Washington Community School Districts	Iowa	4	Soydiesel*	School buses
	Total		40		

*70 percent soydiesel/30 percent diesel blend

Table A-9: Vehicles in the Heavy-Duty Grant Program: Phase 3 School Bus and Heavy-Duty Vehicle Grants

Phase	Operating Jurisdiction	State	Number	Fuel	Vehicle Type
3	Washington, D.C.	District of Columbia	4	CNG	Ford E350s
3	Boston	Massachusetts	4	CNG	Airport shuttles
3	Long Beach	California	4	CNG	Refuse haulers
3	State of Maryland	Maryland	7	CNG	Heavy-duty vehicles
3	Kenosha	Wisconsin	3	CNG	Refuse haulers
3	Kenosha	Wisconsin	1	CNG	Street sweeper
3	Chicago	Illinois	7	Diesel, LPG, Ethanol, CNG	Refuse haulers
3	Las Vegas	Nevada	2	CNG	Street sweepers
3	Phoenix	Arizona	2	CNG	Tractor trailers
3	Phoenix	Arizona	2	CNG	Dump trucks
3	Phoenix	Arizona	2	CNG	Refuse haulers
3	State of Pennsylvania	Pennsylvania	1	M100	School bus
3	State of Pennsylvania	Pennsylvania	1	CNG	School bus
3	Austin	Texas	2	LPG	Refuse haulers
	Total		42		

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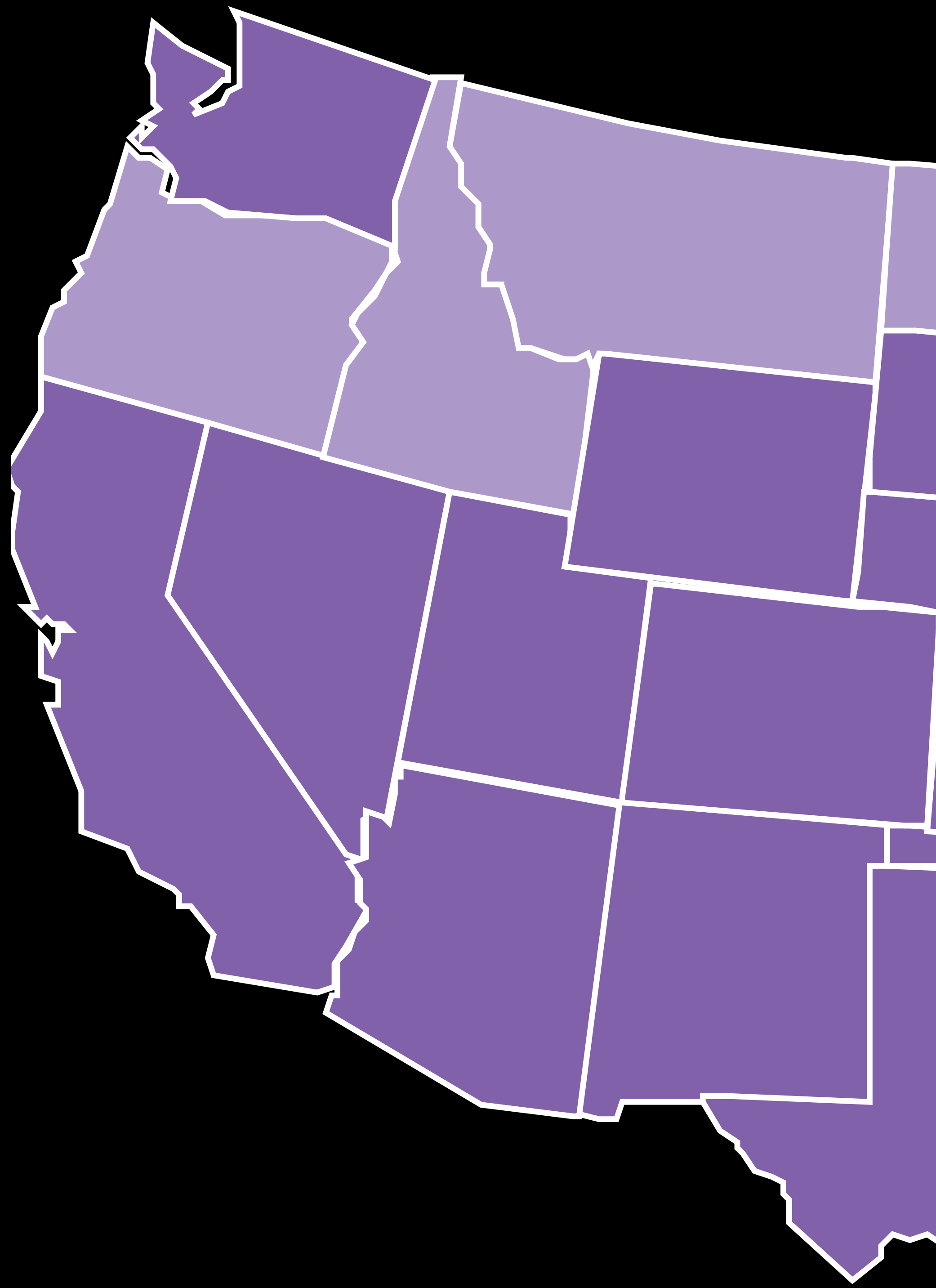

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