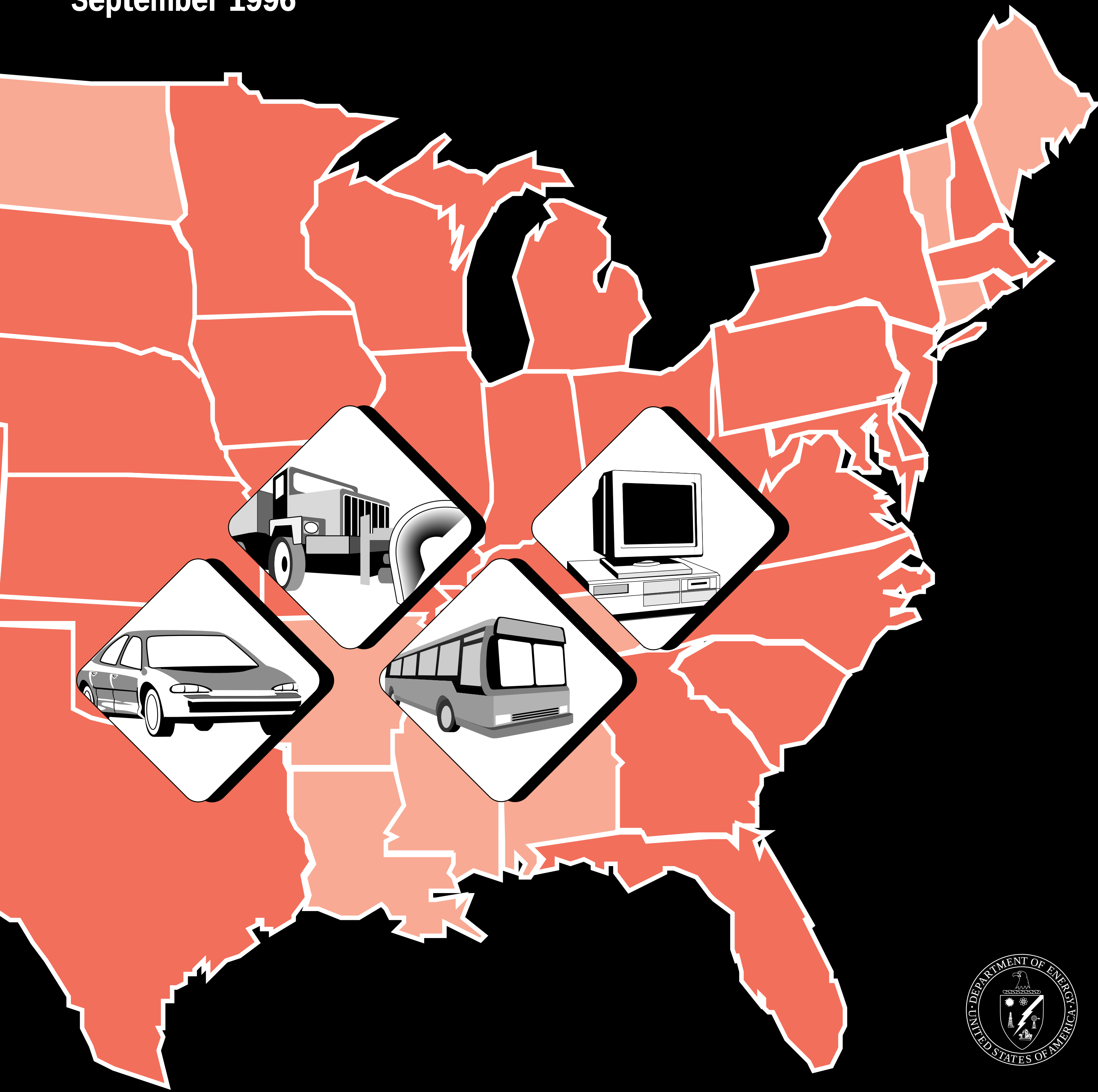
Federal Alternative Motor Fuels Programs

Fifth Annual Report to Congress

September 1996



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

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Alternative Fuels Data Center Internet Address -
http://www.afdc.doe.gov

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Acknowledgments

The U.S. Department of Energy gratefully acknowledges the cooperation of the participating Federal agencies in the Alternative Motor Fuels Programs—the General Services Administration; the National Highway Traffic Safety Administration and the Federal Transit Administration (which are both entities within the U.S. Department of Transportation); 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. The many organizations 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 U.S. Department of Energy's alternative fuel vehicle demonstration and performance tracking programs being conducted across the country in accordance with the Energy Policy and Conservation Act (42 U.S.C. 6374, et seq.). These programs, which comprise the most comprehensive data collection effort ever undertaken on alternative transportation fuels and alternative fuel vehicles, are beginning their sixth year. This report summarizes tests and results from the fifth year. Even though present interest in electric vehicles is quite high, they are not currently included in these vehicle demonstration and performance tracking programs, and the annual report does not include information on them.

Since the inception of the programs, great strides have been made in developing commercially viable alternative fuel vehicle technologies, these achievements having been accomplished in large part as a result of the Department of Energy's direct encouragement and support. However as is the case in the commercialization of all new technologies, some performance problems have been experienced on vehicles involved in early demonstration efforts.

Substantial improvements have been recorded in vehicle practicality, safety, and performance in real-world demonstrations, especially during the past year. An aspect of particular interest is emissions output. To date, results from light-duty alternative fuel vehicles procured from original equipment manufacturers and operating in the Federal fleet have demonstrated superior in-service emissions performance. In addition, heavy-duty alternative fuel vehicles have demonstrated dramatic reductions in particulate emissions. On the other hand, emissions results from vehicles converted to run on alternative fuel have not been as promising. These and other findings are available through the Department of Energy's Alternative Fuel Data Center World Wide Web site (http://www.afdc.doe.gov).

Although the technologies available today are already commercially viable in some markets, further improvements in infrastructure and economics will result in greater market expansion and an attendant increase in the number of vehicles deployed. To this end, the Department of Energy plans to continue its efforts to foster additional growth toward technically and economically viable alternatives to petroleum-based transportation fuels.

Through these and other alternative fuels programs, and with the assistance of its staff and technology

The Fuels Being Tested

In all, the three programs being managed by the U.S. Department of Energy are testing five kinds of alternative fuels—methanol, ethanol, compressed natural gas, liquefied natural gas, and propane—plus biodiesel. What are these 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 for 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.

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 the three-carbon molecule 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.

Biodiesel. As tested in this program, biodiesel (B20) is actually a low-level blend of 20 percent diesel derived from biomass, microalgae, or agricultural waste and 80 percent conventional diesel. 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. However, only B100 (neat biodeisel) is currently considered by the U.S. Department of Energy to be an alternative fuel under the definition contained in the Act.

partners around the country, the U.S. Department of Energy continues to make significant contributions toward achieving the national goals of increasing energy security, reducing trade deficits, creating more domestic jobs and industries, and promoting cleaner air.

Summary of Results

Light-Duty Vehicles

The Federal light-duty vehicle demonstration program studies emissions, vehicle performance, and fuel economy on passenger cars, minivans, and light vans and trucks that operate on alternative fuels. This effort is focused on meeting the requirements of section 400 AA of the Energy Policy and Conservation Act (The Act). At the Federal level, alternative fuel vehicles are required to be purchased from the original equipment manufacturers and placed in service throughout the Federal fleet.

The number of alternative fuel vehicles in the Federal fleet has grown to nearly 20,000. For cost effectiveness, and to minimize the impact on day-to-day government operations, data are collected only on a sample of this number. The light-duty vehicle test program is currently collecting data from 337 vehicles that operate on one of the alternative fuels, plus 146 vehicles that operate only on reformulated gasoline (the control group).

New models added in program year 1995 include the 1995 Dodge Caravan, a dedicated compressed natural gas vehicle, and the 1995

Dodge Intrepid, a flexible-fuel vehicle operating on 85 percent methanol. Information obtained from the analysis of light-duty vehicle data through August 1995 includes emissions, performance and reliability, fuel economy, and cost.

Emissions

Emissions measurement is the single most comprehensive part of the test program for light-duty vehicles. The effort being undertaken is also the most extensive and carefully controlled study of emissions of alternative fuel vehicles in the world. Phase I testing began in 1991 and lasted through 1994. To obtain results from a wider range of alternative fuel vehicles at a higher level of statistical reliability, the number and types of vehicles tested were greatly increased under Phase II of the program.

Average emissions from the four-cylinder methanol Dodge Spirits are well below the Federal emissions standards for non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen. The regulated exhaust emissions from the ethanol tests on the variable fuel vehicles were 15 percent to 20 percent lower than those from the reformulated gasoline tests on the same vehicles. Analysis from the first round of testing of the Dodge B250 vans indicates notably lower emissions of regulated exhaust pollutants from the compressed natural gas vehicles in contrast to those produced by the standard gasoline vehicles. The exhaust emissions from the flexible-fuel Ford Econoline vans tested on methanol were lower than, or similar to, the exhaust emissions of those same vehicles when tested on reformulated gasoline.

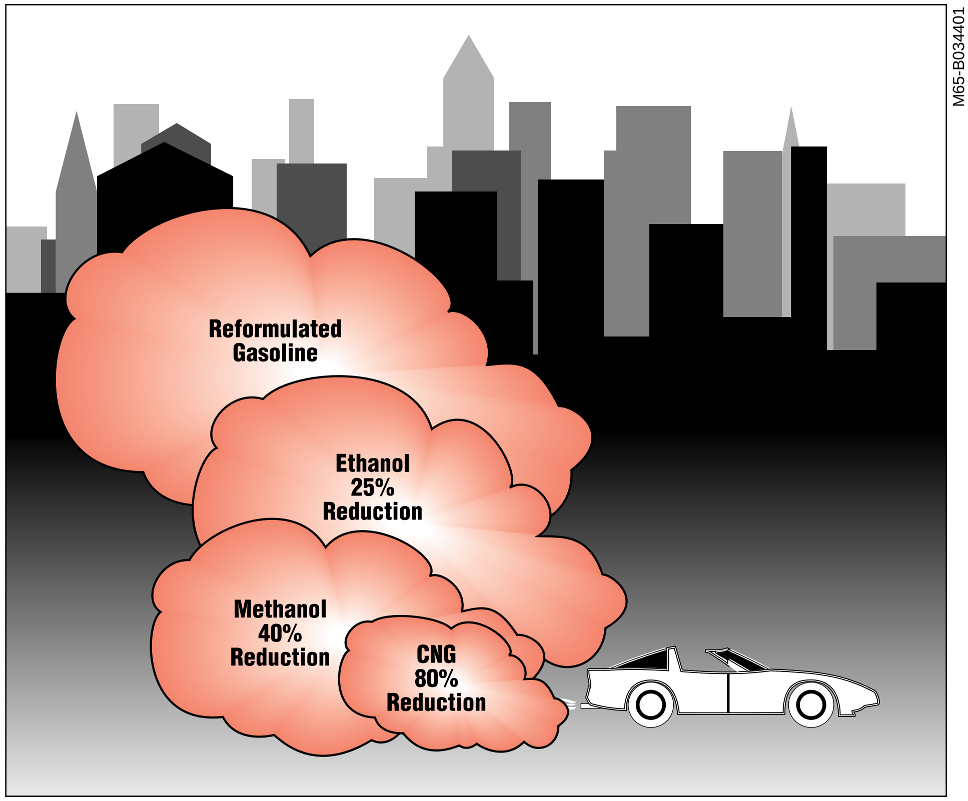

Figure 1. Reduction in light-duty vehicle urban ozone-forming potential attributable to alternative fuels

The urban ozone-forming potential calculated from the alternative fuel vehicle emissions was substantially less than their reformulated gasoline counterparts. Urban ozone-forming potential was reduced 25 percent, 40 percent, 50 percent, and 80 percent for the ethanol Chevrolet Luminas, the methanol Dodge Spirits, the methanol Ford Econoline vans, and the compressed natural gas Dodge B250 vans, respectively. These results are illustrated in Figure 1.

Performance and Reliability

Information has been collected regarding the performance and reliability of alternative fuel vehicles, and their standard gasoline counterparts, for nearly four years. As expected, drivers reported more performance problems, on average, for the early-model alternative fuel vehicles than for the later-model vehicles. From the drivers' perspective, the performance of alternative fuel vehicles in general has improved with time, and is now nearly equal to the accepted performance level of gasoline vehicles.

Fuel Economy

Testing of vehicles on a chassis dynamometer, and analysis of refueling records from actual daily use, have resulted in two sources of fuel economy information. In the first case, information is obtained on each vehicle at the time of emissions testing on a chassis dynamometer. In the second case, actual in-use fuel economy is calculated using refueling records maintained in the Department of Energy's Alternative Fuels Data Center at the National Renewable Energy Laboratory. During actual use, vehicle fuel economy varies considerably because of individuals' driving styles and a number of other factors, such as the type of driving (stop-and-go city driving, highway driving, deliveries, or a combination of all three), climate, and altitude. On an equivalent energy basis, vehicles operating on alternative fuels tend to achieve levels of fuel economy that are similar to those achieved by standard vehicles operating on gasoline.

Cost

Total vehicle cost includes initial acquisition, insurance, maintenance, fuel, and oil.

The information available to date on alternative fuel vehicles in the Federal light-duty vehicle demonstration program indicates the cost of acquiring those vehicles ranges up to 25 percent higher than the cost of comparable gasoline vehicles. For flexible-fuel vehicles in particular, the price increases range between $0 to $800, depending on the manufacturer. For compressed natural gas vehicles, the price increase can be as much as $5,000 per vehicle.

In September 1995, retail pump fuel prices across the country ranged from approximately $1.60 to $1.87 per gallon of 85 percent ethanol, $2.00 to $2.88 per gallon of 85 percent methanol, $0.60 to $1.14 per gallon of compressed natural gas, and $1.10 to $1.18 per gallon of regular unleaded gasoline. These price ranges account for differences in fuel energy content and reflect the alternative fuel cost on a per-gallon-of-gasoline equivalent basis.

Most maintenance on General Services Administration vehicles is done under warranty at no cost to the fleet operator (except for lost time in service). Therefore, data on the actual cost of maintenance, and a summary of average maintenance costs per mile, are not yet available. Analysis of information available to date indicates that the number of unscheduled repairs on alternative fuel vehicles decreases with each new model year. This evidence, along with growing experience, increases the confidence that in the long-term, average maintenance costs for alternative fuel vehicles will approach those of standard gasoline vehicles.

Transit Buses

The Federal transit bus demonstration program (section 400 CC of the Act) is designed to provide a comprehensive study of the alternative fuels currently used by the transit bus industry. The following eight metropolitan areas were selected for program participation: Houston, Texas; Miami, Florida; Minneapolis, Minnesota; New York, New York; Peoria, Illinois; St. Louis, Missouri; Tacoma, Washington; and Portland, Oregon. Buses used by the transit agencies of these municipalities are being operated on, and are undergoing a number of tests on, four different alternative fuels—compressed natural gas, liquefied natural gas, methanol, ethanol—plus B20 (a low-level blend of 20 percent biodiesel and 80 percent conventional diesel fuel). Only B100 (neat biodiesel) is considered an alternative fuel under the Act.

The alternative fuel engines included in the transit bus demonstration program are: Detroit Diesel 6V92TA methanol engine; Detroit Diesel 6V92TA ethanol engine; Detroit Diesel 6V92TA pilot ignition natural gas engine; Cummins L10G natural gas engine. All transit buses are 35-foot or 40-foot models manufactured by Mercedes, Flxible, Gillig, TMC, and BIA.

Emissions

With funding from the U.S. Department of Energy, 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 transportability of this chassis dynamometer allows a large number of emissions tests on transit buses and heavy-duty vehicles to be conducted around the country on site.

During 1995, West Virginia University personnel traveled to transit agency facilities in New York City, Miami, Peoria, St. Louis, Minneapolis, Tacoma, and Portland, Oregon, to test transit buses included in the Federal demonstration program.

These tests conducted by West Virginia University show that emissions of particulate matter are reduced to nearly zero in engines fueled with compressed natural gas. This is an important and attractive feature of this fuel that reduces the amount of black smoke emanating from city buses. Transit buses fueled by ethanol and methanol also emit lower particulate matter levels than otherwise identical diesel buses (see Figure 2).

The tests conducted to date show that emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen from alternative fuel transit buses vary more than expected. In some cases, emissions were lowered, but high-emitting alternative fuel vehicles were also found. To identify the sources of the problems, teams of experts were brought together to diagnose and repair high emitters. These teams were comprised of representatives from the National Renewable Energy Laboratory, West Virginia University, the engine manufacturers, and their affected transit agencies. This work helped explain

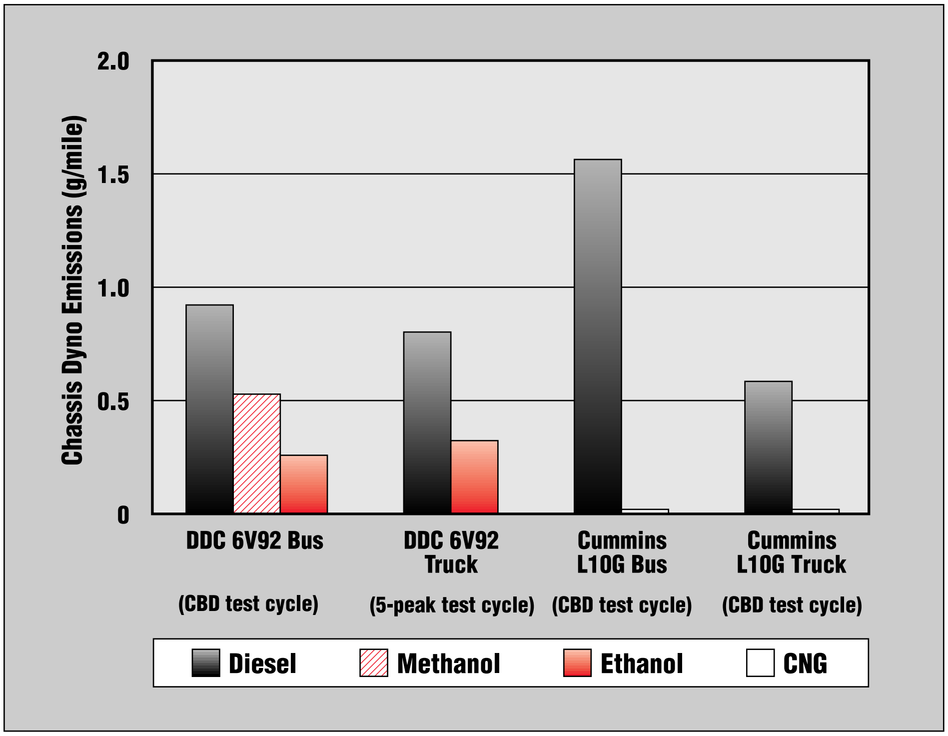

Figure 2. Summary of heavy-duty vehicle particulate emissions results

the causes for high emissions and resulted in dramatic reductions at two transit sites.

West Virginia University's emissions testing activities have helped to underscore two very important points. First, by participating in demonstration programs, transit agencies can play an important role in developing technologies that will help to improve air quality. Second, the diagnosis and repair of high emitters have shown that, even though the use of alternative fuels may reduce emissions, engine technology and proper vehicle maintenance are also crucial factors.

Performance and Reliability

A common measure of transit bus reliability is the number of road calls that are required for every 1,000 miles each vehicle travels. Information on the road calls per 1,000 miles of operation for vehicles in the Federal transit bus demonstration program show the alternative fuels to be quite similar to their diesel counterparts in most locations.

Fuel Economy

Fuel economy and fuel costs are very important to transit agencies because these elements represent a significant portion of the total expense of operating a transit bus. Approximately half the total cost (excluding driver costs) of operating a diesel transit bus is directly attributable to fuel economy and fuel cost.

The average fuel economy for liquefied natural gas/diesel dual-fuel transit buses was approximately 16 percent less than the average fuel economy for their diesel counterparts. Most of this reduction in fuel economy is likely attributable to problems with the engine.

The average fuel economy of the compressed natural gas transit buses from dynamometer and on-road tests is about 10 percent to 20 percent lower than the corresponding average fuel economy for their diesel counterparts. This reduction is within the expected range, as the compressed natural gas engines use a spark-ignited design as opposed to the more efficient compression-ignition design of the diesel engines.

With regard to the fuel economy of alcohol transit buses, the results to date indicate that the vehicles at all the sites are performing very well, delivering fuel economy comparable to that of their diesel counterparts on an energy equivalent basis.

Cost

There are incremental costs associated with operating alternative fuel transit buses. These costs can be aggregated into increased capital outlays and increased operating expenses. Increased capital outlays are attributable to the additional costs (if any) of acquiring alternative fuel transit buses and modifying facilities.

Increased operating expenses are due to a larger number of factors. A breakdown of the estimated total operating costs for a typical large transit agency such as the ones participating in the Federal transit bus demonstration program includes driver labor, vehicle maintenance, administration, and fuel expense. Driver labor costs represent more than half the total.

One common measure, fuel cost per mile, is calculated using average in-use fuel economy and the actual fuel cost paid by the transit agencies. For transit buses operating on compressed natural gas, the fuel and maintenance costs per mile are about the same as those for transit buses operating on diesel. However, for transit buses operating on an alcohol fuel or B20 (a low-level biodiesel blend not considered by the U.S. Department of Energy to be an alternative fuel under the Act), the same costs are up to twice as high as those for transit buses operating on diesel. The fuel and maintenance costs for transit buses operating on dual-fuel liquefied natural gas/diesel are about 25 percent higher than for their diesel counterparts.

Heavy-Duty Vehicles

The Federal heavy-duty demonstration program (section 400 BB of the Act) includes two types of vehicles: medium-sized commercial delivery vans and large trucks (such as line-haul tractor trailers and garbage packers). In total, some 170 delivery vans and large trucks are included in the program. With regard to the medium-sized delivery vans, vehicles in two commercial delivery fleets are included: Federal Express and United Parcel Service. The Federal Express vehicles are evaluated in the CleanFleet project, which is coordinated by Battelle Memorial Institute. The U.S. Department of Energy also manages a grant program that supports states in their purchases of heavy-duty alternative fuel vehicles. The vehicles in the grant program are located all across the country, representing vehicle vocations that range from street sweepers to school buses.

Emissions

During 1995, 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 ethanol line-haul trucks in Illinois, Hennepin County's ethanol snowplows in Minnesota, and AG Processing Corporation's line haul trucks operating on B20, the biodiesel blend, and diesel. A number of diesel control vehicles with the same engine configurations were also tested at each of the sites. Particulate emissions results from this test program on heavy-duty trucks are summarized in Figure 2.

The use of alternative fuels in heavy-duty trucks can substantially reduce particulate matter emissions. The average of particulate matter from the ethanol trucks in the Federal heavy-duty demonstration program is less than 50 percent of the corresponding value for their diesel counterparts. On the other hand, the average particulate matter emissions from the compressed natural gas vehicles is very low. In six of eleven tests performed to date, particulate matter levels are essentially zero (i.e., too low to measure), and the diesel vehicles average approximately 0.7 grams per mile.

Emissions information has also been obtained from the Federal Express CleanFleet project. In this project, 36 delivery vans (actually medium-duty vehicles) were emissions tested at each of three different mileage levels.

The CleanFleet compressed natural gas vehicles emitted an average of 65 percent to 80 percent less carbon monoxide than otherwise identical vehicles running on gasoline. These vehicles also had 70 percent to 95 percent lower non-methane hydrocarbon emissions. Emissions of oxides of nitrogen were mixed.

The difference in emissions from delivery vans operating on propane and those from their counterparts operating on gasoline became more pronounced with increasing mileage. Generally, the average emissions levels from the propane vans remained relatively constant, but the gasoline control vans exhibited increasing values with increasing mileage.

The overall results from the Ford vans running on 85 percent methanol were highly variable; but, in general, these vehicles tend to exhibit lower average carbon monoxide emissions than their gasoline counterparts.

Performance and Reliability

Vehicle performance for heavy-duty trucks and commercial delivery vans encompasses such factors as acceleration, hill climbing, driveability, and driver acceptance. To directly assess the performance of heavy-duty trucks operating on alternative fuels, acceleration and hill climbing capability of a compressed natural gas line-haul truck operated by Vons Grocery Company, and a diesel counterpart, were measured. Acceleration for the two trucks was nearly identical.

Fuel Economy

All fuel economy data for the CleanFleet delivery vans have been collected and analyzed. The Chevrolet propane and compressed natural gas vans and Dodge compressed natural gas vans achieved 10 percent to 15 percent lower in-use fuel economy than their gasoline counterparts on an energy equivalent basis. The fuel economy achieved by all the Ford vehicles (compressed natural gas, propane, and 85 percent methanol) was within a few percentage points of the fuel economy achieved by their gasoline counterparts on an energy equivalent basis. So far, most of the alternative fuel large trucks have exhibited both in-use and dynamometer fuel economy comparable to their diesel counterparts.

Cost

As expected, equipping a prototype or early-production heavy-duty truck to use alternative fuels is more expensive than equipping a similar truck to operate on diesel. As the heavy-duty alternative fuel market develops, such costs are expected to decrease.

In principle, no alternative fuel engine should be inherently more expensive to manufacture than a diesel engine. In contrast, the fuel tanks for compressed natural gas will probably continue to be more expensive. However, this is a relatively small part of the total cost of the vehicle.

A small incremental cost for the fuel system could easily be recovered in lower fuel costs. Fuel cost is generally a large part of the total operating cost of a trucking company—second only to personnel costs. As noted previously, the cost of alternative fuels varies from one fuel to another, both regionally and over time. Federal and state taxes also figure heavily into fuel cost.

Virtually all the heavy-duty, alternative fuel vehicles in the Federal demonstration program cost more to maintain than their diesel counterparts. Most of the vehicles in the program represent prototype, field-test technology, and part of the reason for deploying and tracking them is to work out the bugs in the technology so they can be moved closer to commercialization. Higher maintenance costs are to be expected for such vehicles. As alternative fuel engine manufacturers accumulate experience through such programs, the reliability of the engines will increase and maintenance costs should approach those of their diesel counterparts.

Aftermarket Vehicle Conversions

The Energy Policy Act of 1992 (42 U.S.C. 13212 (a) and (b)), which amends the Act, specifies minimum purchase requirements for alternative fuel vehicles in the Federal fleet. Although alternative fuel vehicles have been under development for more than ten years, their availability from the automotive manufacturers was not sufficient in calendar year 1992 to allow the various Federal agencies to meet the requirements of the Act. “Aftermarket conversions” were chosen to fill the gap until a sufficient number of original equipment models could be made available at a reasonable cost.

The conversion effort has succeeded in helping the Federal government meet the requirements of the Act during a period of otherwise uncertain supply. Original equipment availability has since improved, however.

At this time, light-duty vehicles may be converted to operate on one of two alternative fuels—natural gas or liquefied petroleum gas (propane). Each aftermarket vehicle conversion is protected by a warranty that covers all installed conversion system parts and associated labor for three years or 36,000 miles, whichever comes first. As required by the provisions of the Act, subcontractors signed individual warranty agreements with Chrysler, Ford, and General Motors.

The first light-duty vehicle conversions were completed during the summer of 1994. Conversion activities are continuing through the date of this writing.

Most light-duty vehicle conversions (more than 92 percent) are bi-fuel conversions, which means that the vehicle may operate on either gasoline or the designated alternative fuel. The average total cost for each compressed natural gas conversion in the program is about $4,500. The average total cost for each liquefied petroleum gas conversion, on the other hand, is about $2,700.

Emission Results

Aftermarket conversions can play an important role in the transition to more widespread use of alternative fuel vehicles. However, the emissions performance to date of these relatively advanced conversion systems raises questions about their overall emissions contribution to the environment. There are plans for further testing in 1996 to help answer these questions.

Infrastructure Support

To meet the demands that the increasing numbers of alternative fuel vehicles are placing 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 the components of the alternative fuel industry together. Growth of this infrastructure has been stimulated by various legislative 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. Also, the Department of Energy has promoted infrastructure development within the context of its Clean Cities program.

Expanded development of refueling sites faces a number of hurdles, depending on the alternative fuel of interest. For methanol and ethanol refueling stations, it is relatively easy to install a new in-ground or aboveground fuel storage tank. Special attention must be given to the choice of materials used.

For compressed natural gas, all such options are more expensive than those for alcohol fuels. A slow-fill system uses a small compressor and has the lowest cost. A fast-fill system, on the other hand, requires a large and expensive compressor station. Most public access compressed natural gas stations are fast-fill, but they can cost $200,000 to $300,000 to build.

All of the above considerations notwithstanding, the number of alternative fuel refueling stations continues to increase. As of August 1, 1995, there were more than 1,100 compressed natural gas stations, 88 methanol stations, and 36 ethanol stations. The total number of alcohol and natural gas refueling sites for alternative fuels has more than quadrupled in the past five years. The Liquefied Petroleum Gas Clean Fuels Coalition recently estimated that there are now as many as 11,000 sites where propane can be obtained for this purpose.

Transit bus agencies and heavy-duty fleet operators generally install their own fueling stations and do not use public facilities.

The General Services Administration reports that, as a rule, alternative fuel vehicle maintenance was sometimes difficult in the early years of the program (1991–1992), but is no longer the problem it once was.

The infrastructure for alternative fuel vehicles is growing at a pace that parallels the number of alternative fuel vehicles being deployed. No significant impediment to further expansion is evident.

Vehicle Availability

The number of light-duty alternative fuel vehicles operating in U.S. Federal and non-Federal fleets has increased steadily over the past several years. The Energy Information Administration projects an increase in ethanol flexible-fuel vehicles to nearly 32,000 units in the near future because of an announcement that Chevrolet will manufacture an ethanol-compatible pickup truck.

Light-duty vehicles fueled by liquefied petroleum gas are estimated to be the largest group of vehicles in the United States operating on a fuel other than gasoline. The best information currently available puts the total at approximately 217,000 units.

In January 1995, a survey of transit bus agencies was conducted by the American Public Transit Association. The survey results indicate that, of the more than 52,000 buses currently in operation around the country, about 3 percent of them now operate on alternative fuels.

In 1995, the light-duty manufacturers offered six compressed natural gas models (including dedicated minivans, pickups, a dedicated van, a bi-fuel van, and a bi-fuel pickup), two 85 percent ethanol flexible-fuel sedans, and one liquefied petroleum gas heavy-duty truck. The models available in 1996 will include one 85 percent ethanol sedan, six compressed natural gas vehicles (including dedicated minivans, pickups, vans, and sedans), a bi-fuel van, a bi-fuel pickup, and one liquefied petroleum gas medium-duty truck.

The Energy Policy Act (42 U.S.C. 13212 (b) (1) (A)) mandates that 25 percent of all new vehicle purchases made in fiscal year 1996 by the Federal government must be alternative fuel vehicles. Based on projected vehicle acquisitions, the General Services Administration will be required to purchase approximately 8,600 units.

Information Dissemination

Information dissemination is an important component in the Department of Energy's program to expand the use of alternative fuels in the United States. Accurate, timely, and readily available information can only help to hasten public acceptance and adoption of alternative fuels and alternative fuel vehicles. The legislation requiring these activities includes the Alternative Motor Fuels Act of 1988, the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, and Executive Order 12844.

To make the best possible use of all the information being collected through the various vehicle demonstration programs, the Office of Alternative Fuels in the Department of Energy's Office of Transportation Technologies established the Alternative Fuels Data Center at the National Renewable Energy Laboratory. This center serves as the focal point for the information collected in all the vehicle demonstration programs. The Alternative Fuels Data Center maintains information on line in computerized databases, although hard copies are available as well, that are distributed through the National Alternative Fuels Hotline (1-800-423-1DOE). Several methods are available for accessing information in the Alternative Fuels Data Center. The primary method is via the World Wide Web on the Internet (http://www.afdc.doe.gov).

Background

Establishing the Programs

In 1988, Congress passed the Alternative Motor Fuels Act, Public Law 100-94, which added sections 400 AA–400 EE to the Energy Policy and Conservation Act (42 U.S.C. 6374 et seq.) (the Act). Recognizing that displacing 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.

With the additions noted above, the Act directs the U.S. Department of Energy to cooperate with other Federal agencies to acquire and operate vehicles that use alternative fuels. It also requires 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 Congress an annual report of that study (42 U.S.C. 6374 (b) (1) and (3)) (the sidebar on page 15 summarizes the provisions of the Alternative Motor Fuels Act). This is the fifth 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 a nationwide effort (Figure 3) encompassing three programs of study:

- *The Alternative Fuels Light-Duty Demonstration Program.* In this program, established under section 400 AA of the Act (42 U.S.C. 6374), the General Services Administration, in conjunction with the Department of Energy, 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 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 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

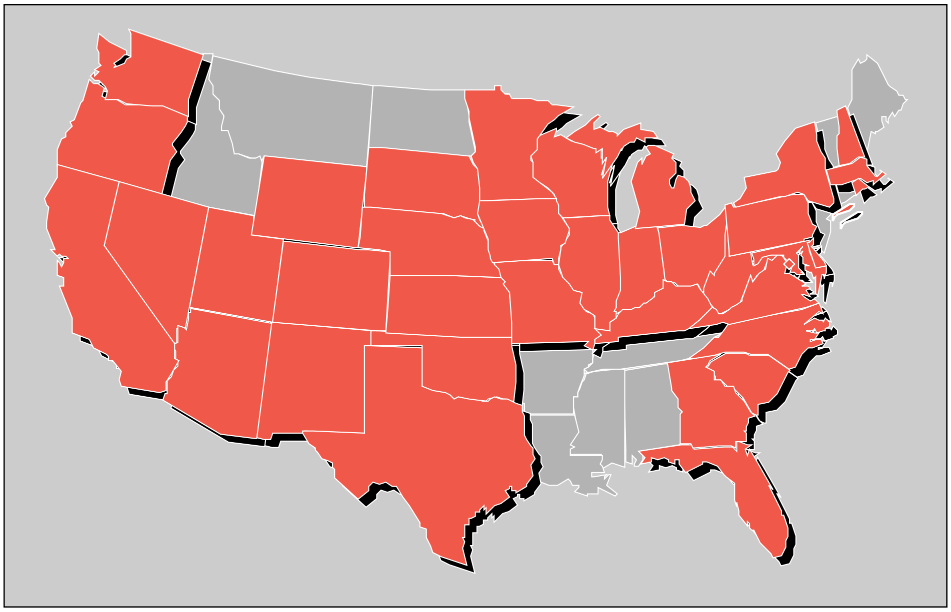

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Figure 3. Alternative fuel vehicles included in the Department of Energy's demonstration and performance tracking programs are located in the states highlighted in green.

only on the fuel for which they are designated. Those dedicated vehicles operating on gasoline are control vehicles that serve as a baseline for comparison.

- *The Alternative Fuels Transit Bus Demonstration Program.* In this program, established under section 400 CC 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 transit buses in eight municipalities across the nation.

  Vehicles are tested with engines and fuel systems designed to run on methanol, ethanol, liquefied natural gas and compressed natural gas. Standard diesel transit buses running on B20 are also tested (B20 is a low-level biodiesel blend not currently considered by the Department of Energy to be an alternative fuel under the provisions of the Act).

  Transit buses running on conventional diesel fuels are used as a basis for comparison. Some of the transit buses that run on liquefied natural gas require diesel fuel as a pilot ignition source. All the other types of alternative fuel transit buses are dedicated to run on the fuel for which they are designed.

  The transit bus test program should prove quite valuable for transit authorities. According to a survey conducted by the American Public Transit Association, the transit bus sector of the market is well ahead of other sectors in the market penetration of alternative fuel vehicles. Approximately 1,600 transit buses in the United States run on alternative fuels, representing about 3 percent of the bus market. Until the inception of the Department of Energy's program, no systematic data had been collected on operation and maintenance of these vehicles. Also, a transit bus is an ideal application of alternative fuels because it is centrally refueled (requiring less infrastructure development), and because extra space is generally available on a bus to store the sometimes bulky fuel tanks. This suggests that the market for alternative fuel vehicles could grow faster for transit 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 demonstration program, it was established under section 400 BB 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 cost of the test vehicles is shared with private fleet owners, or with state or local governments. The heavy-duty trucks included in the program are modified to run on methanol, ethanol, compressed natural gas, or biodiesel. The goal is to help develop new alternative fuel engines and trucks (most heavy-duty alternative fuel engine development is still in the prototype stage).

For commercial vans, two delivery fleets are being tracked: 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. Data are being collected from these vehicles and compared with information collected from vehicles using similar engines, but operating on 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 entities 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 light-duty vehicles to be used in the programs and distributes them to the various Federal agencies, which use them in their fleets, and participate in the testing programs.

The Alternative Motor Fuels Act of 1988

In 1988 Congress passed the Alternative Motor Fuels Act, which added Sections 400 AA–400 EE to the Energy Policy and Conservation Act (the Act). The Alternative Motor Fuels Act encourages—

(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 other agencies 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;

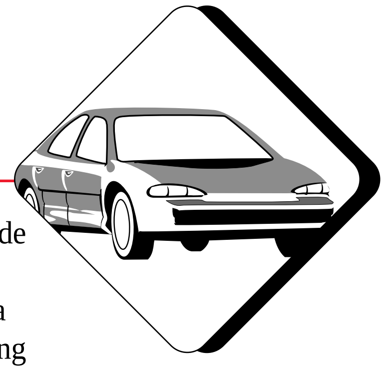
(ii) the fuel economy, safety, and emissions of such vehicles; and,

(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.

- The Environmental Protection Agency sets regulations for emissions and defines standard methods for measuring those emissions.
- 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 test the engines and vehicles and collect data, which they send to the Alternative Fuels Data Center.
- 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 transit 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 transit buses.
- Some municipalities cooperate in the program for testing heavy-duty vehicles. Most are interested in exploring options to relieve pollution, and thus help prove and test the vehicle. As an example of municipal applications, garbage trucks are operated and maintained that run on alternative fuels. Information on these vehicles is forwarded to the Alternative Fuels Data Center for compilation.
- Various 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 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 staff members travel 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 transit buses.
- Drivers of many of the test vehicles gather data on refueling, mileage in real-world situations, and problems encountered.

Light-Duty Vehicles



Overview

The Federal light-duty vehicle evaluation program studies emissions, vehicle performance, and fuel economy on passenger cars, minivans, and light vans and trucks that operate on alternative fuels. This effort is focused on meeting the requirements of section 400 AA of the Energy Policy and Conservation Act (the Act). At the Federal level, the General Services Administration, in cooperation with the Department of Energy, purchases alternative fuel vehicles from the original equipment manufacturers under the requirements of the Act, and provides such vehicles throughout the Federal fleet. A number of the General Services Administration's vehicles are included in the light-duty vehicle evaluation program.

U.S. automobile manufacturers currently provide light-duty vehicles that operate on compressed natural gas or alcohol fuels (85 percent ethanol and 85 percent methanol). Vehicles designed to operate on compressed natural gas can be "dedicated," meaning they can only be operated on that fuel, or "bi-fuel." The bi-fuel compressed natural gas vehicles are equipped to carry both gasoline and natural gas, and can switch between operation on the two fuels.

A number of vehicle design modifications are required to enable the various vehicle models to operate on a gaseous fuel. The changes include replacing the fuel tank with high-pressure gas cylinders, installing a new fuel injection system, changing the engine to make it compatible with the gaseous fuel, and adding other equipment related to fuel management, such as pressure relief devices.

All compressed natural gas vehicles in the General Services Administration fleet, and included in the light-duty vehicle evaluation program, are dedicated vehicles.

In contrast, the alcohol-fuel vehicles in the Federal fleet are also known as "flexible-fuel" vehicles. As implied in its name, a flexible-fuel vehicle can run on gasoline alone or on various blends of alcohol and gasoline, depending on the vehicle design, up to a maximum of 85 percent ethanol or methanol. Relatively minor design modifications are needed to turn a standard gasoline vehicle into one that can operate on an alcohol fuel. Changes include using alcohol-resistant materials in the fuel system, adding a fuel sensor, and

Photo by Warren Gretz, NREL/PIX 03314

This minivan runs on compressed natural gas.

replacing the engine microprocessor with one designed to control the varying fuel blends. All alcohol vehicles currently in the Federal light-duty vehicle evaluation program are flexible-fuel vehicles.

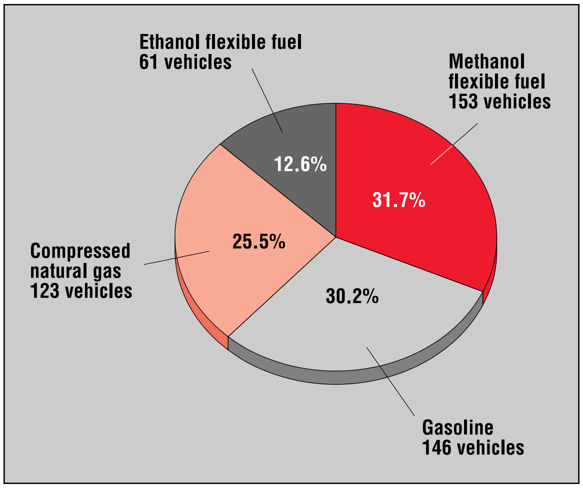
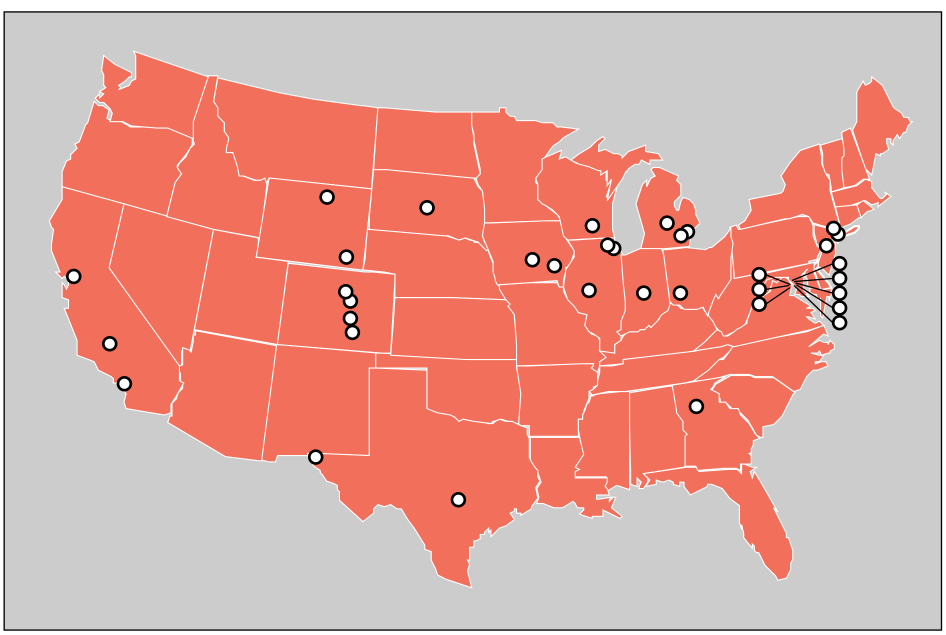


Figure 4. Light-duty vehicles in the 1995 evaluation fleet

Based on its budget, and on vehicle availability, the General Services Administration purchases as many alternative fuel vehicles as possible for its annual vehicle replacement program. These vehicles are leased to Federal agencies and their contractors for normal Federal service.

In addition to its alternative fuel vehicle purchase requirements, the Act requires various data to be collected from a sample of vehicles in the Federal fleet. The number of alternative fuel vehicles in the Federal fleet has grown to nearly 20,000. For cost effectiveness, and to minimize the impact on day-to-day government operations, data are collected only on a sample of this number. The light-duty vehicle program is currently collecting data from 337 vehicles that operate on one of the alternative fuels, plus 146 vehicles that operate only on gasoline (the control group). The number of test vehicles in the program fueled with each of the alternative fuels is depicted in Figure 4. The sample includes different vehicle models located at various sites around the country (see Figure 5) to allow the program to assess the impact of higher altitudes on emissions and the impact of climatic conditions on various aspects of vehicle performance.

Figure 5. Locations of light-duty vehicles in the 1995 evaluation fleet



The automobile manufacturers' alternative fuel vehicle offerings have been altered each model year. To keep up with vehicle design changes and technical advances, the light-duty vehicle test program adds new models to the data collection effort each year. New models added in program year 1995 include the 1995 Dodge Caravan, a dedicated compressed natural gas vehicle, and the 1995 Dodge Intrepid, a flexible-fuel vehicle operating on 85 percent methanol.

The General Services Administration has followed a policy of removing passenger cars from service after three years, and vans and trucks after six years. In accordance with this policy, some 1992 Chevrolet Luminas operating on ethanol were removed from the program in 1995. Fourteen of these vehicles continue in service. Additional modifications were made to the test fleet in 1995 to improve the overall program design and to more adequately reflect available vehicle models, as well as usage of each alternative fuel.

As the light-duty vehicle evaluation program progresses and evolves each year, experience with alternative fuel vehicles continues to grow. This growth in experience is evidenced by the number of cumulative miles traveled by all vehicles in the program over time (see Figure 6).

In addition, data are collected directly from vehicle drivers, the General Services Administration, and emissions laboratories. Drivers report mileage, fuel usage, and performance problems. Maintenance and repair data are extracted from General Services Administration records. Periodically, as vehicles reach various mileage levels, a subset of the vehicles is removed from service for emissions testing. Laboratories approved by the Environmental Protection Agency perform these tests.

The following sections summarize information obtained from the analysis of light-duty vehicle data through August 1995. Included are discussions on emissions, performance and reliability, fuel economy, and cost.

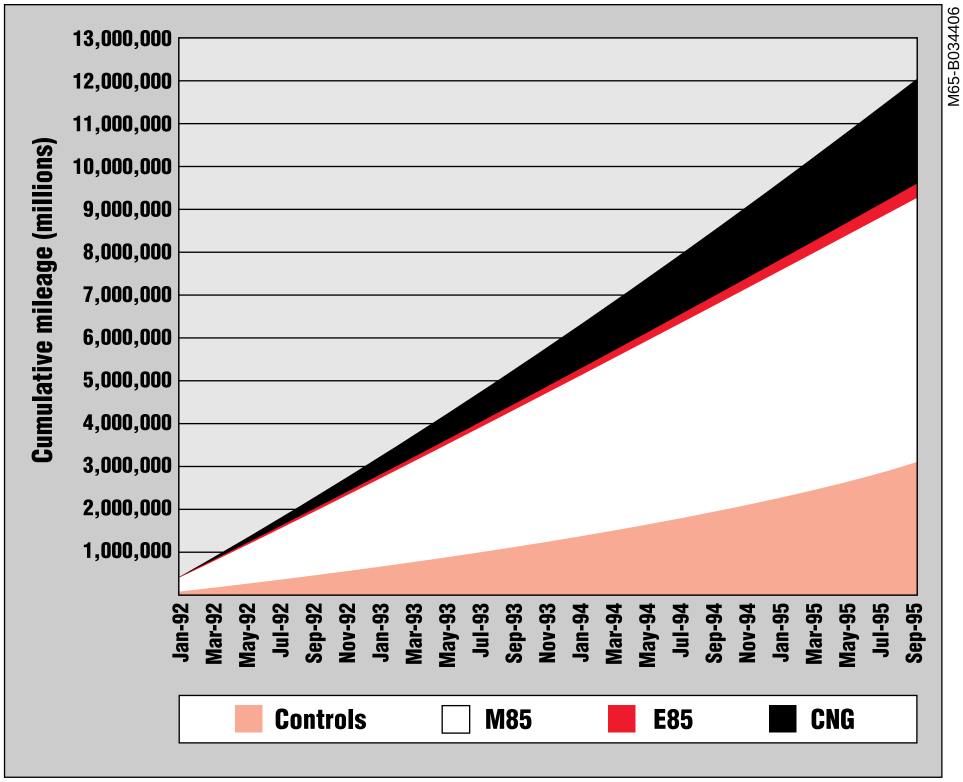


Figure 6. Mileage accumulation on light-duty vehicles in the demonstration program

Abbreviations

B20 = 20 percent biodiesel blend

B35 = 35 percent biodiesel blend

B100 = neat biodiesel

CBD = Central Business District

CNG = Compressed natural gas

CO = Carbon monoxide

E50 = 50 percent ethanol

E85 = 85 percent ethanol

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

E95 = 95 percent ethanol

g/mile = grams per mile

HC = Hydrocarbons

LNG = Liquefied natural gas

M50 = 50 percent methanol

M85 = 85 percent methanol

M100 = 100 percent methanol

NMHC = non-methane hydrocarbons

NO_x = Oxides of nitrogen

OMNMHCE = Organic material non-methane hydrocarbon equivalent

PM = Particulate matter

RF-A = Industry average standard unleaded test gasoline

RFG = Reformulated gasoline

WVU = West Virginia University

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), and ethyl tertiary butyl ether (an ethanol-based ether).

To compare alternative fuels to clean-burning gasoline, reformulated gasoline was used as the base case in the light-duty 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.

Emissions

Emissions measurement is the single most comprehensive part of the test program for light-duty vehicles. The effort undertaken in the Federal program 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, are divided into two parts: Phase I and Phase II.

Phase I Emissions Testing

Phase I testing began in 1991 and lasted through 1994. Eighteen vehicles were tested during this phase: seven flexible-fuel Luminas, two gasoline Luminas, seven flexible-fuel Tauruses, and two gasoline Tauruses. Each vehicle was tested at odometer readings of approximately 4,000 and 10,000 miles, and subsequently at approximate 10,000-mile intervals. Nationally recognized facilities tested the vehicles using chassis dynamometers (see sidebar, page 21) to measure exhaust emissions according to the Federal Test Procedure—Code of Federal Regulations, Title 40, Part 86, Emissions Certification and Test Procedures. Testing on these vehicles was concluded when the General Services Administration removed the vehicles from its fleet.

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 the results obtained, the conclusions presented were limited. Phase II was designed to build on information obtained in Phase I.

Phase II Emissions Testing

To obtain results from a wider range of alternative fuels at a higher level of statistical reliability, the number and type of vehicles tested were greatly increased. In addition, a full suite of speciated exhaust emissions results was obtained on approximately 15 percent of these vehicles (see sidebar on page 22).

For Phase II, a competitive procurement was used to select the privately owned laboratories that were to

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 it is going through a driving cycle, then another evaporative emissions test after it 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 tests 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 vehicle off for 10 minutes, restarts it, and 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.

Photo by Warren Gretz, NREL/PIX 03322

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 the first round of testing, the laboratories subjected 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 four minutes. Originally designed for private vehicles, this test was done with the vehicle at operating temperature because cars were warmed up when they came in for emissions testing. To determine the value of the inspection and maintenance 240 test for low-emissions alternative fuel vehicles, the program correlated its results with those of the 40-minute test.

Hydrocarbon Speciation

All hydrocarbons are not created equal. Although the Environmental Protection Agency has specific emissions certification standards for hydrocarbons, there is also a wide array of other compounds in vehicle exhausts that are *classified* as hydrocarbons. Some hydrocarbons, such as benzene and 1,3-butadiene, are considered to be more toxic than others. Individual hydrocarbon compounds are also assigned reactivity factors, which indicate their likelihood of reacting with oxides of nitrogen in the atmosphere to form smog. Other compound gases—known as aldehydes and alcohols—are oxygenated derivatives of hydrocarbons. They are of interest because they may directly affect human health, or may contribute to the formation of ozone.

The Environmental Protection Agency's emissions regulations on hydrocarbons take some of these factors into account. For instance, because methane has a very low photochemical reactivity factor, the hydrocarbon certification standards are written in terms of non-methane hydrocarbons. In the case of alcohol fuels (methanol and ethanol), the most recent hydrocarbon regulations include non-methane hydrocarbons, plus a fraction of the aldehydes and alcohols. This value is known as organic material non-methane hydrocarbon equivalent.

The Federal emissions testing program is furthering the understanding of the differences in hydrocarbons from various alternative and conventional fuels by measuring and evaluating the relative levels of aldehydes, alcohols, and methane in the exhaust emissions. This analysis requires special equipment—gas chromatographs, liquid chromatographs, and alcohol impingers—which are not usually found in a basic emissions test facility.

The most comprehensive analysis of hydrocarbons is called hydrocarbon speciation. In this analysis, hundreds of hydrocarbon compounds found in the vehicle emissions are quantified. The results from hydrocarbon speciation analysis are being used in the Federal emissions testing program to compare the relative potential for hydrocarbon emissions from the various fuels to form smog, based on reactivity factors specified by the California Air Resources Board. This information is also being used as input for the research and development efforts at the National Renewable Energy Laboratory, which is involved in modeling atmospheric reactions.

perform emissions testing. The selection criteria included technical expertise (including experience in testing alternative fuel vehicles), proximity to the test fleets, and cost. Environmental Research & Development was selected 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 allows for a high-altitude comparison on emissions performance.

The laboratories test the vehicles at the same approximate odometer readings as in Phase I, using chassis dynamometers and the Federal Test Procedure. They also use the

Photo by Warren Gretz, NREL/PIX 03321

An exhaust sample being connected to a gas chromatograph for a detailed hydrocarbon analysis

Environmental Protection Agency's inspection and maintenance 240 test procedure (see sidebar, page 21). Phase II also differs from Phase I in that several types of vehicles are now being tested: flexible-fuel vehicles capable of running on 85 percent ethanol or 85 percent methanol; dedicated vehicles running on compressed natural gas; and control vehicles running on gasoline. In the emissions testing program, reformulated gasoline, California Phase II Certification Fuel (see sidebar on page 20), is used as the basis of comparison to alternative fuels.

To compare emission levels at various fuel-mixing ratios, flexible-fuel vehicles have been tested 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 selection of alcohol used in the mixtures depends on whether the vehicle is designed to run on ethanol or methanol.

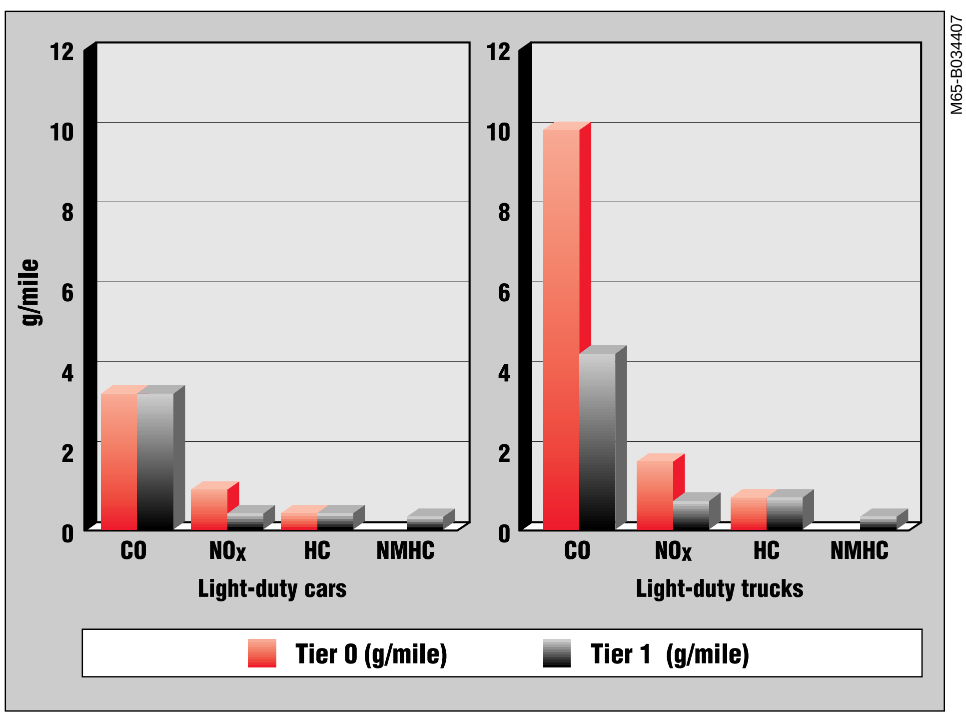
Vehicles dedicated to operating on compressed natural gas are tested on fuel blended from tightly controlled constituent gases (93.05 percent methane, 3.41 percent ethane, 0.65 percent propane, etc.). This test fuel is designed to represent an industry-average product.

Exhaust emissions from vehicles operating on alternative fuels and reformulated gasoline are compared to the Federal standards, which mandate the maximum allowable levels on a grams per mile basis. The regulated components are hydrocarbons, carbon monoxide, and oxides of nitrogen.

Between 1994 and 1998, new standards are being phased in. These standards regulate 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 and does not add to photochemical smog. However, methane is considered to be a highly potent greenhouse gas—far more active than carbon dioxide.

By 1998, 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 7. Tier 0 and Tier 1 emissions standards for light-duty vehicles. (Note that NMHC is not regulated in the Tier 0 standards.)



Phase II Preliminary Emissions Results

As of August 1, 1995, 803 emissions tests had been conducted on 215 alternative fuel vehicles, and 287 emissions tests had been conducted on 175 gasoline control vehicles. These totals include tests on multiple fuels, and repeat tests on individual vehicles. Table A-1 in the Appendix lists the numbers of each vehicle model tested and the number of tests conducted on each model. As part of the experimental design, each alcohol fuel vehicle is tested on each of three fuel combinations every time the vehicle is brought in for testing.

The first round of testing on the initial Phase II vehicles is complete, as is about half of the second round. The first round of testing was also begun in 1995 on three new vehicle models representing the latest alternative fuel offerings from Chrysler, Ford, and General Motors. An extensive engineering and statistical analysis on the first-round data is in progress. The results of this analysis will be subjected to peer review by experts in the alternative fuels and automotive industries. Some preliminary findings are presented below.

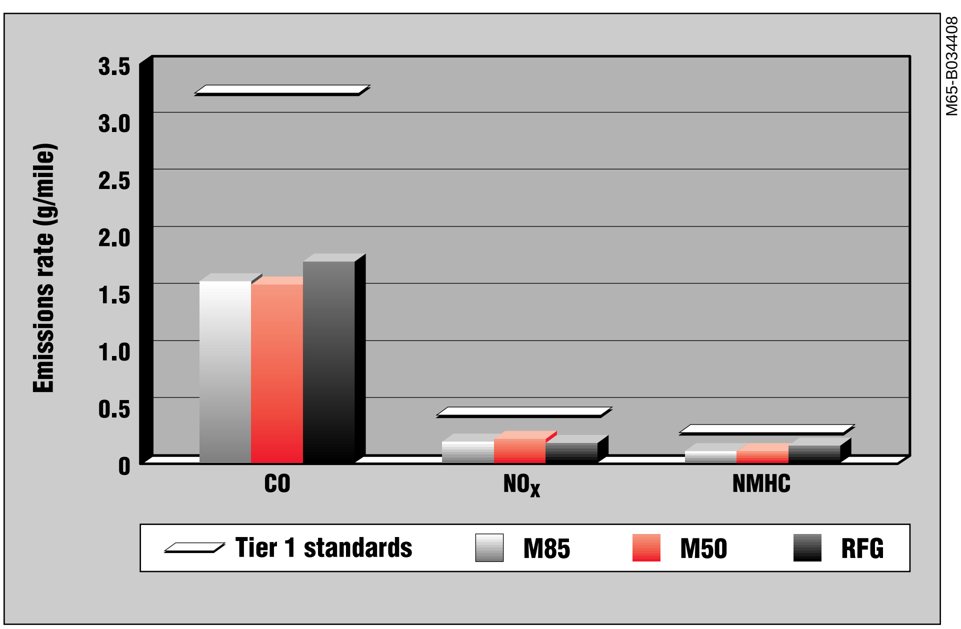
Results from Methanol Dodge Spirits

The most extensive testing to date has been conducted on Dodge Spirits: 319 emissions tests on 76 methanol flexible-fuel models, and 126 tests on 72 standard gasoline models. As shown in Figure 8, the preliminary average emissions from these four-cylinder passenger cars are all below the Tier 1 standards for non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen.

On average, flexible-fuel Dodge Spirits tested on 85 percent methanol or 50 percent methanol showed a modest reduction (approximately 10 percent) in non-methane hydrocarbons in comparison to the corresponding values obtained on reformulated gasoline. The Dodge Spirits emitted very similar levels of carbon monoxide and oxides of nitrogen when tested on alcohol compared to the same levels emitted when tested on reformulated gasoline.

Because non-methane hydrocarbons represent a class of pollutants rather than one specific compound, further analysis is required. To provide the necessary additional information, a full hydrocarbon speciation analysis was performed on approximately 15 percent of the exhaust measurements from Dodge Spirits (see sidebar on page 22). Preliminary results show that the hydrocarbon profiles for the alcohol fuels are much

Figure 8. Emissions results from methanol flexible-fuel Dodge Spirits



different than those for reformulated gasoline. For instance, the average levels of benzene and 1,3-butadiene (hydrocarbon compounds considered to be air toxics) are far lower than the corresponding levels from the reformulated gasoline. On the other hand, the average formaldehyde emissions from the methanol tests were substantially higher than those from the reformulated gasoline.

Finally, hydrocarbon speciation allows for a relative comparison to be made between fuels on the potential for exhaust hydrocarbons to react in the atmosphere to form ozone. Early results of this type indicate that the exhaust hydrocarbons emitted from the flexible-fuel Dodge Spirits have, on average, approximately 40 percent lower ozone-forming potential than those emitted from the same vehicles operating on reformulated gasoline.

Results from Ethanol Chevrolet Luminas

As of August 1, 1995, 101 emissions tests had been conducted on 25 variable-fuel Chevrolet Luminas, and 48 tests had been conducted on 24 standard gasoline Chevrolet Luminas. The preliminary average emissions from the six-cylinder Chevrolet Luminas were all below the Tier 1 emissions standards for non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen (see Figure 9).

On average, the regulated exhaust emissions from the ethanol tests on the variable-fuel vehicles were 15 percent to 20 percent lower than those from the reformulated gasoline tests on the same vehicles. Because

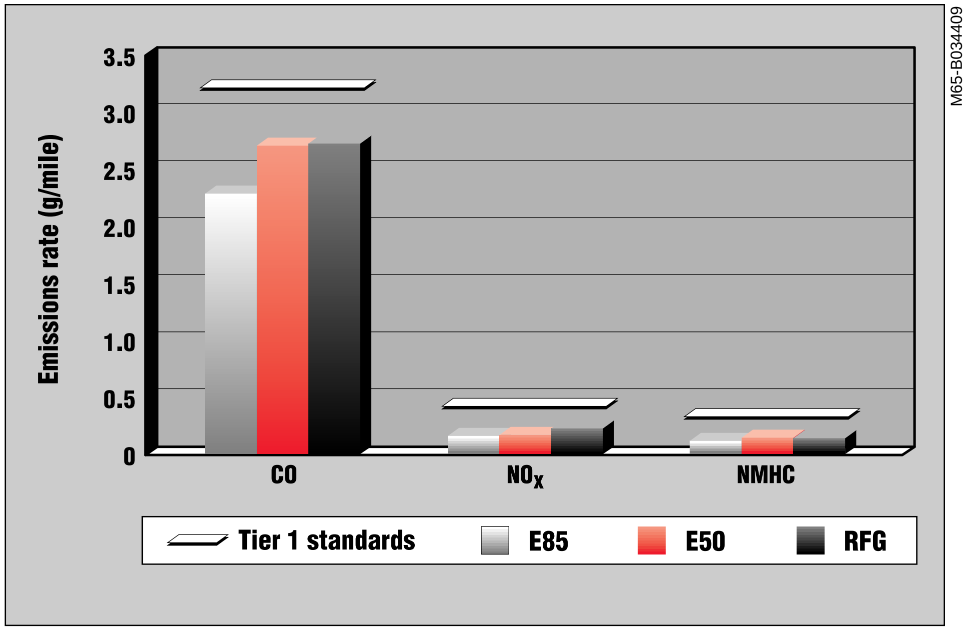


Figure 9. Emissions results from ethanol flexible-fuel Chevrolet Luminas

the three test fuels (85 percent ethanol, 50 percent ethanol, and reformulated gasoline) for these vehicles were blended to have similar vapor pressures (nominal 7 pounds per square inch), very little difference in average evaporative emissions was observed.

Preliminary results from full hydrocarbon speciation of exhaust measurements on approximately 15 percent of the Chevrolet Luminas show a substantially different hydrocarbon profile between ethanol and reformulated gasoline. Average emissions of air toxics, such as benzene and 1,3-butadiene, were approximately 80 percent lower from the ethanol tests than from the reformulated gasoline tests. Ethanol formaldehyde emissions were up slightly on average, and ethanol acetaldehyde emissions were far higher, on average, in comparison to the corresponding average emissions from the reformulated gasoline tests. The potential for the hydrocarbon emissions to form ozone, expressed in average

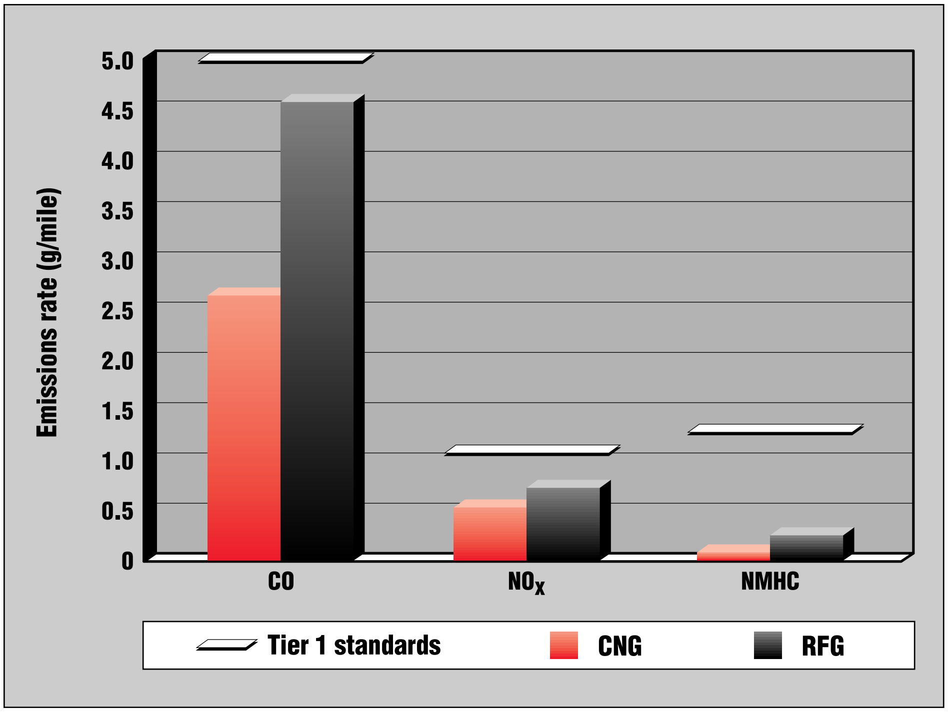


Figure 10. Emissions results from gasoline and compressed natural gas Dodge B250 vans

milligrams of ozone per mile, was approximately 25 percent lower, on average, from the ethanol tests than from the reformulated gasoline tests.

Results from Dodge B250 Vans

As of August 1, 1995, 66 emissions tests had been performed on 52 dedicated compressed natural gas Dodge B250 vans, and 60 tests had been performed on 47 standard gasoline Dodge B250 vans (the control group).

On average, preliminary analysis from the first round of testing indicates notably lower emissions of regulated exhaust pollutants from the compressed natural gas vehicles, in contrast to those produced by the standard gasoline vehicles. Nonmethane hydrocarbons were approximately 70 percent lower, carbon monoxide was approximately 40 percent lower, and oxides of nitrogen were approximately 30 percent lower, on average, than the corresponding levels observed for the standard gasoline vehicles. The average results, along with the appropriate Federal standards, are depicted in Figure 10.

To address concerns over natural gas fuel system leaks, an enhanced test procedure for CNG vehicles was developed. A leak test similar to the standard evaporative test performed on all liquid fuel vehicles (see sidebar on page 21) was added.

The leak tests performed on the compressed natural gas vehicles showed that some vehicles did, in fact, have small fuel leaks, but the amounts were comparable to, or lower than, the total hydrocarbons evaporating from the standard gasoline vehicles. While the vehicle manufacturer has been informed of this finding, the size of the leaks is not expected to pose a safety risk.

The full speciation of exhaust hydrocarbons from four of the compressed natural gas vehicles and five of the gasoline vehicles indicates that the compressed natural gas hydrocarbon profile is very different from that of reformulated gasoline. On average, emissions of toxic hydrocarbons, such as benzene and 1,3-butadiene, were approximately 95 percent lower in the tests on compressed natural gas vehicles than in the tests on reformulated gasoline vehicles. The average formaldehyde emissions were 10 percent higher in the tests on compressed natural gas vehicles than in the tests on reformulated gasoline vehicles, but one of the four compressed natural gas vehicles had much higher formaldehyde emissions than all the others, which increased the overall average. On average, formaldehyde emissions from the compressed natural gas vans would otherwise have also been lower than those from reformulated gasoline vans. The potential for hydrocarbon emissions to form ozone, expressed in average milligrams of ozone per mile, was approximately 80 percent lower in the tests on compressed natural gas vehicles than in the tests on reformulated gasoline vehicles.

Results from Methanol Ford Econoline Vans

The first round of testing of methanol flexible-fuel Ford Econoline vans was completed during 1995. This included 62 tests on 16 flexible-fuel vans and 23 tests on 18 standard gasoline vans. The average exhaust emissions results from these full-size passenger vans were all below the respective Tier 1 standards (see Figure 11). On average, the exhaust emissions from the flexible-fuel van tested on methanol were lower than or similar to the exhaust emissions of those same vehicles when tested on reformulated gasoline. Non-methane hydrocarbons were approximately 10 percent lower, carbon monoxide was approximately 30 percent lower, and oxides of nitrogen were about the same.

Full speciation of the exhaust hydrocarbons from approximately 15 percent of the tests on Ford Econolines indicates, once again, that the methanol hydrocarbon profile is very different than the reformulated gasoline hydrocarbon profile. On average, emissions of toxic hydrocarbons, such as benzene and 1,3-butadiene, were between 60 percent and 80 percent lower in the methanol tests than in the reformulated gasoline tests on the same vehicles. The average formaldehyde emissions were approximately five times higher in methanol tests than in the reformulated gasoline tests on the same vehicles. The potential for hydrocarbon emissions to form ozone, expressed in average milligrams of ozone per mile, was approximately 50 percent lower in the methanol tests than in the reformulated gasoline tests on the same vehicles. The relative difference between the methanol and reformulated gasoline hydrocarbon profiles obtained from the exhaust emissions of these vehicles is comparable to the corresponding difference between the methanol and reformulated gasoline hydrocarbon profiles obtained from the exhaust emissions of flexible-fuel Dodge Spirits.

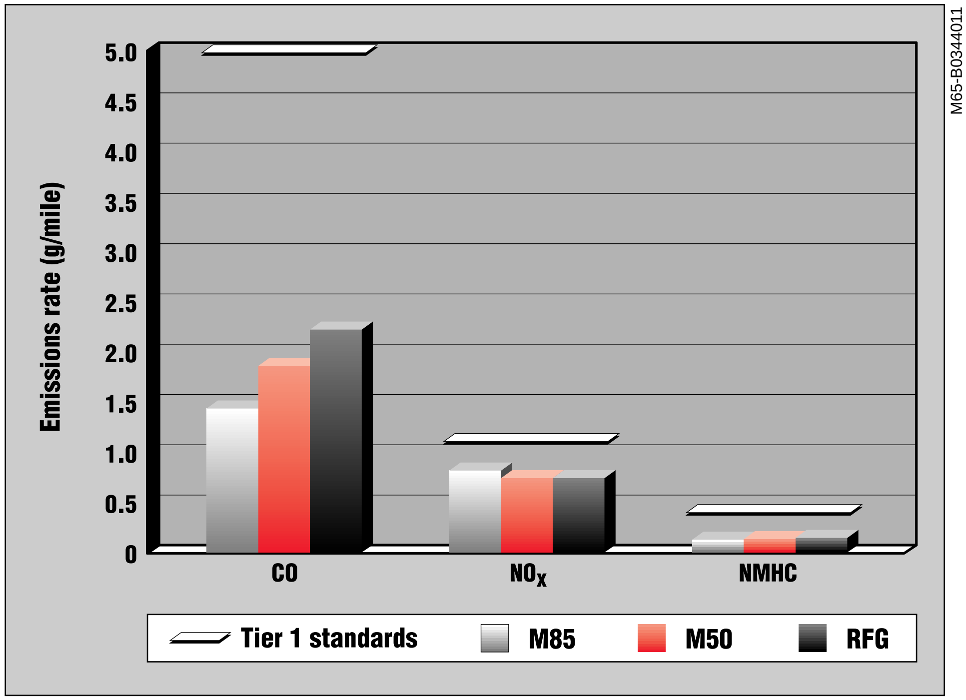


Figure 11. Emissions results from methanol flexible-fuel Ford Econoline vans

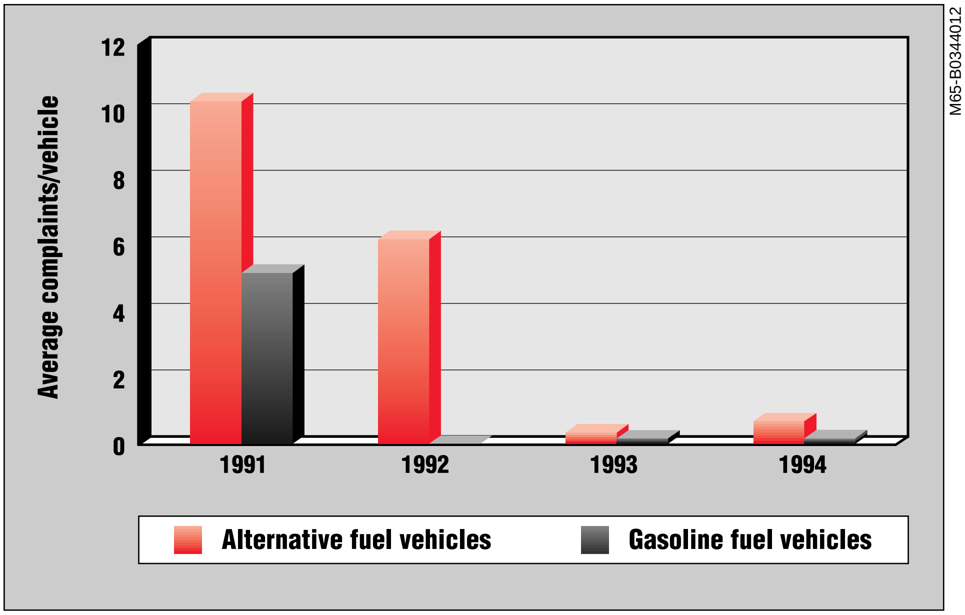
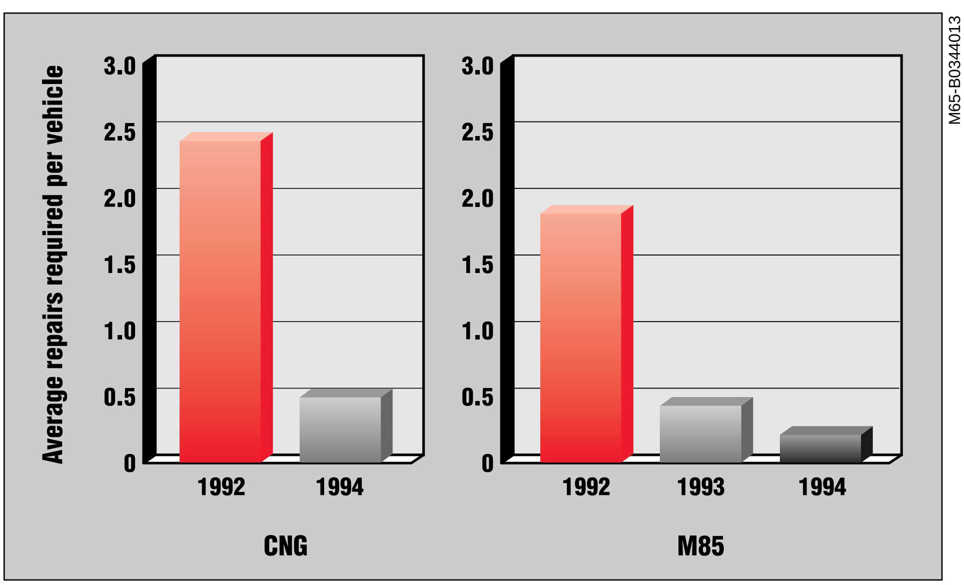


*Figure 12. Driver complaints by model year (reported with less than 10,000 miles on vehicles)**

* Does not include data from 1992 compressed natural gas Chevrolet pickup trucks, which were recalled. Also, there were no driver complaints on the single 1992 gasoline-powered model in the program.

*Figure 13. Reported unscheduled repairs (reported with less than 10,000 miles on vehicles)**

* Does not include data from 1992 compressed natural gas Chevrolet pickup trucks, which were recalled.



Performance and Reliability

The light-duty vehicle evaluation program has been collecting information on the performance and reliability of alternative fuel vehicles, and their standard gasoline counterparts, for nearly four years. Two types of information are being collected and evaluated: driver complaints about various aspects of vehicle performance, and unscheduled repair data, which indicate general vehicle reliability.

Drivers were asked to report whether they experienced any of a number of common performance-related problems when they drove their vehicles. To date, complaints have included hard-starting vehicles, illumination of check-engine light indicators, poor idle quality, hesitation, lack of power, engine ping, and vehicle stalling (after starting or in traffic). As expected, drivers reported more performance problems, on average, for the early-model alternative fuel vehicles than for the later-model vehicles (see Figure 12). From the drivers' perspective, the performance of alternative fuel vehicles in general has improved with time, and it appears to be approaching the accepted performance level of gasoline vehicles.

Unscheduled repairs, which were also relatively frequent on the early model alternative fuel vehicles, are much less so on later models. Figure 13, which shows a comparison of average unscheduled repairs over time for compressed natural gas and methanol vehicles, is indicative of this decline. Such improvements in the unscheduled repair record are believed to result from a combination of vehicle design changes and increased familiarity with alternative fuel vehicles on the part of repair technicians. In most cases, fuel-system-related repairs are covered by the manufacturer's warranty, so excess downtime is the real cost to fleet operators.

In the future, the number of repairs may be further reduced as vehicle designs continue to be optimized, and as replacement parts become more widely available. Conversely, quantity stocking of replacement parts will become more cost-effective as the number of alternative fuel vehicles increases.

Fuel Economy

Testing of vehicles on a chassis dynamometer and analysis of refueling records from actual daily use have resulted in two sources of fuel economy information. In both instances, the calculation of fuel economy to reflect alternative fuel consumption is corrected to "equivalent gallons" of gasoline. One gallon of unleaded gasoline has the same average energy content as 1.77 gallons of 85 percent methanol, or 1.42 gallons of 85 percent ethanol, with the average energy content of unleaded gasoline being 115,000 Btu per gallon (see Figure 14).

Fuel economy information is obtained on each vehicle at the time of emissions testing on a chassis dynamometer. The fuel economy tests generate 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 similar vehicles, which are then averaged to obtain a single value. These average values are shown as points in Figure 15.

Actual in-use fuel economy is also calculated using refueling records maintained in the U.S. Department of Energy's Alternative Fuels Data Center at the National Renewable Energy Laboratory. During actual use, vehicle fuel economy varies considerably because of individual driving style and a number of other factors, such as the type of driving (stop-and-go city driving, highway driving, deliveries, or a combination of all three), climate, and altitude.

Determination of in-use fuel economy is further complicated by the fact that alcohol vehicles, being flexible-fuel vehicles, may be fueled with either alcohol fuel or gasoline at any particular refueling. The gasoline

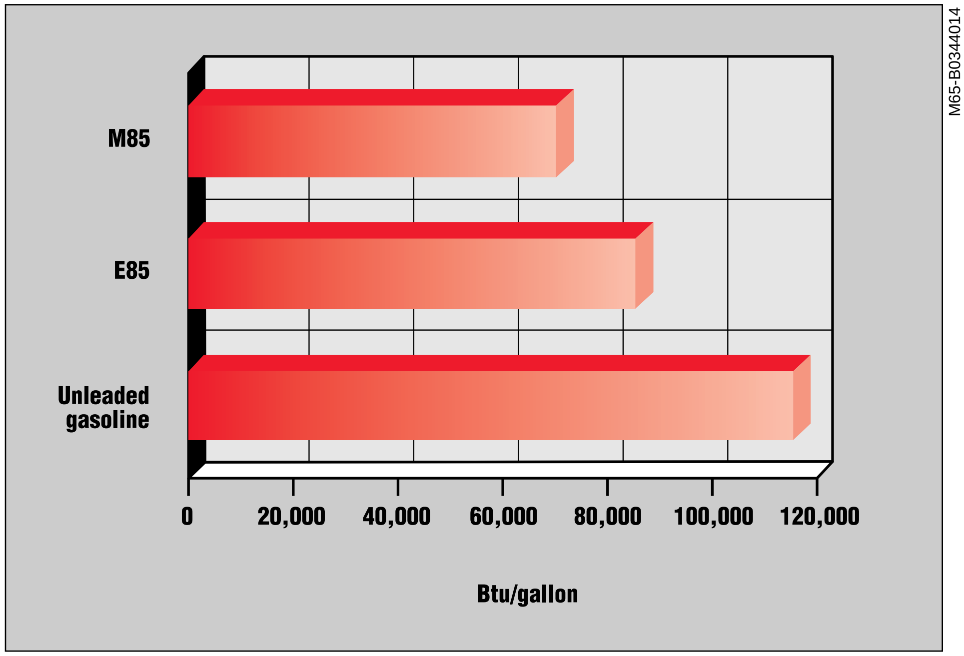


Figure 14. Energy content comparison

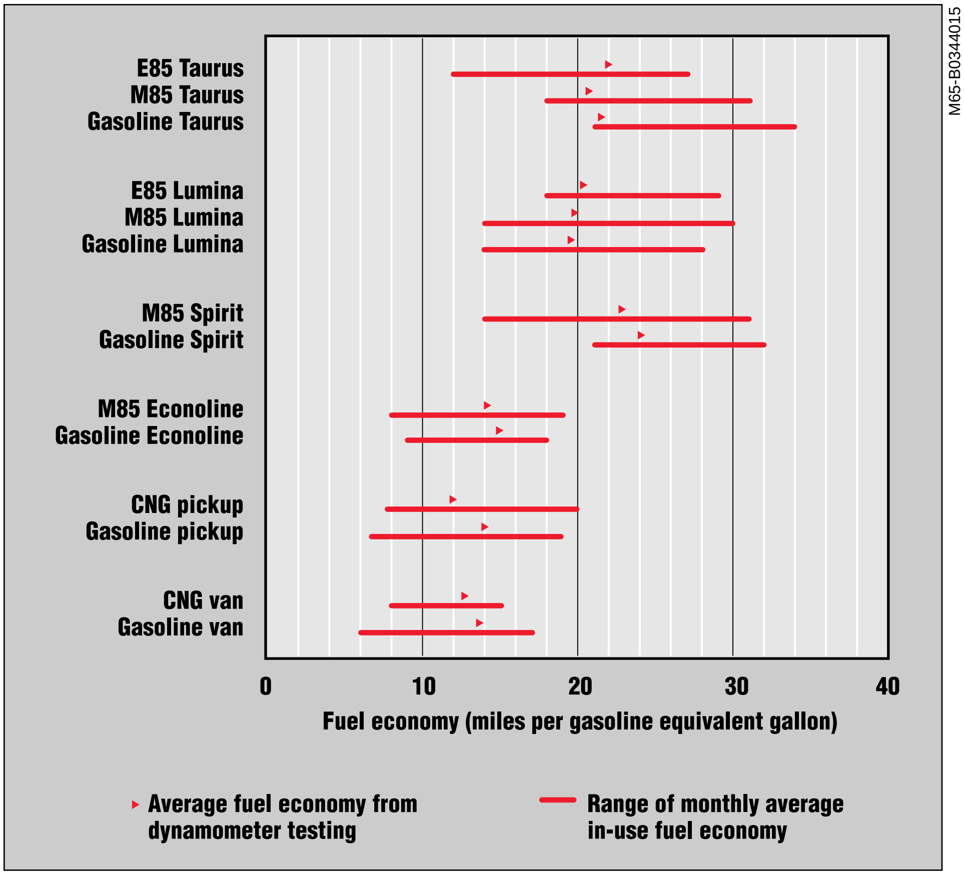


Figure 15. Fuel economy by vehicle type

will mix with the alcohol fuel left in the tank to create a unique blend. To compensate for this situation, in-use fuel economy calculations are based only on instances for which alcohol fuels are used in three consecutive refuels.

A range of results for in-use fuel economy is shown as a line in Figure 15 for various vehicle models in the light-duty evaluation program. In most cases, the figure shows that, on an equivalent energy basis, vehicles operating on alternative fuels tend to achieve levels of fuel economy similar to those achieved by standard vehicles operating on gasoline.

Cost

Obviously, there are costs associated with owning and operating any light-duty vehicle. Total vehicle cost includes initial acquisition, insurance, maintenance, fuel, and oil. The distribution of costs for operating a gasoline-fueled fleet vehicle is depicted in Figure 16. This distribution represents cost over the life of a vehicle, with each component being a composite average for fleets across the United States. These average costs are based on vehicles having been in service an average of 27 months, and having cost an average of $15,000 at the time of initial acquisition. Differences such as self-insurance for government and some private fleets, and how some types of maintenance and repairs are logged, affect the distribution of vehicle costs.

Comparable distributions are likely to be different for a fleet of alternative fuel vehicles. Differences in initial acquisition costs, depreciation costs, and fuel and maintenance costs are expected to affect the overall cost of operating alternative fuel vehicles. For a typical gasoline-fueled fleet, the items included in operating costs (fuel, oil, maintenance, and tires) represent less than 27 percent of the total costs associated with vehicle operation and ownership. The corresponding percentage of total cost that operating cost represents for alternative fuel vehicles is expected to be somewhat higher. However, even if fuel cost for alternative fuel vehicles is 50 percent more than for gasoline vehicles, operating costs would increase to only about 33 percent of the total. The factors that contribute to higher owning and operating costs for alternative fuel vehicles are discussed in more detail below.

Incremental Acquisition Cost

The information available to date on alternative fuel vehicles in the Federal light-duty vehicle evaluation program indicates the cost of acquiring those vehicles ranges up to 25 percent higher than the cost of comparable gasoline vehicles. This price difference is primarily due to the equipment modifications necessary to enable a gasoline model to operate on an alternative fuel. For flexible-fuel vehicles in particular, the price increases range between $0 and $800, depending on the manufacturer. Most of this increase is due to the special fuel system materials required for the alcohol fuels.

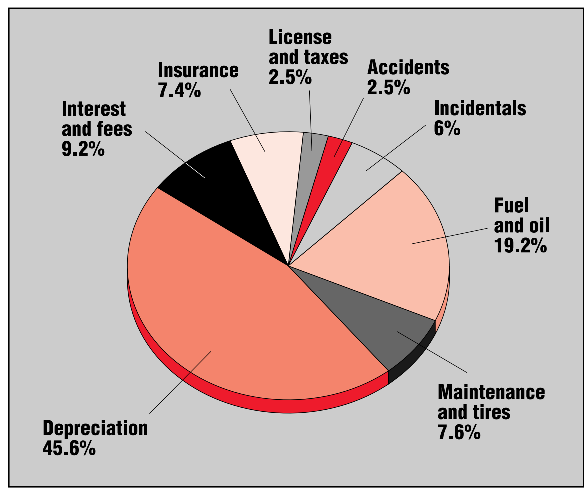
For compressed natural gas vehicles, the price increase can be as much as $5,000 per vehicle. The bulk of this cost increase is attributable to the different fuel storage and intake systems that are necessary to accommodate a gaseous fuel. As the demand for compressed natural gas vehicles increases, the manufacturers will continue to optimize their vehicle designs, which should result in a reduction in the price differential. One automobile manufacturer recently announced a reduction of $750 in the price of its most popular compressed natural gas model.

As is the case for standard gasoline vehicles, the acquisition price for any alternative fuel vehicle will vary depending on the model and options desired. Also, as the initial purchases of alternative fuel vehicles expand, a resale market may begin to grow, with the expectation that some of the additional acquisition costs may be recoverable.

Comparative Fuel Costs

Fluctuations in wholesale prices, and different state and local tax structures, result in a wide variation in fuel costs across the country. Wholesale fuel prices vary as much as $0.20 per equivalent gallon among cities. State and local taxes can add as much as $0.40 per equivalent gallon in certain locales. Some states and communities offer incentives to purchasers of alternative fuels that include reduced tax rates, taxing only the gasoline portion of an alcohol fuel, and taxing all fuels at the same rate as gasoline.

Figure 16. Distribution of operating costs for composite U.S. fleet



Source: PHH Vehicle Management Services

In September 1995, retail pump prices across the country ranged from approximately $1.60 to $1.87 per gallon of 85 percent ethanol, $2.00 to $2.88 per gallon of 85 percent methanol, $0.60 to $1.14 per gallon of compressed natural gas, and $1.10 to $1.18 per gallon of regular unleaded gasoline. These price ranges account for differences in fuel energy content and reflect the alternative fuel cost on a per-gallon-of-gasoline-equivalent basis. They also account for differentials attributable to local variations in taxes or fuel purchasing incentives.

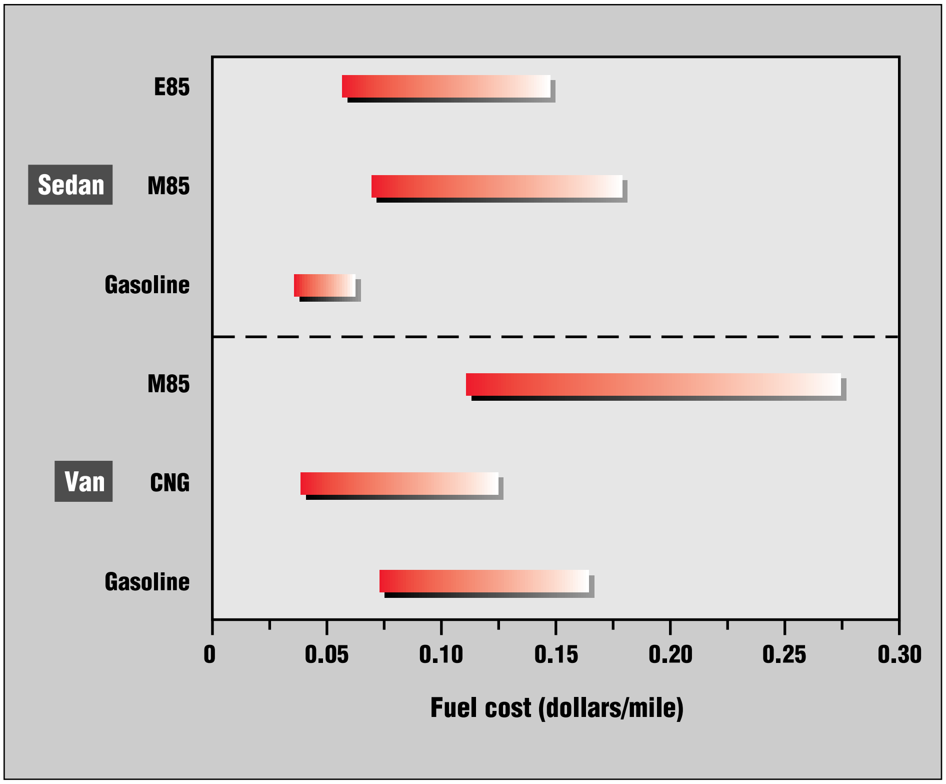


Figure 17. Range of fuel costs per mile (alternative fuel costs are stated on the basis of equivalent gallons of gasoline)

There are a number of industry sources, including *Oxy-Fuel News*, *21st Century Fuels*, and *New Fuels Report*, which track the wholesale and retail prices of the various alternative motor fuels. The U.S. Department of Energy's Energy Information Administration also produces weekly and monthly publications containing information on fuel prices around the country. Many state fuel purchasing incentives are itemized in the Department of Energy's publication entitled *Guide to Alternative Fuel Vehicle Incentives and Laws*.

Variations in fuel costs, as well as variations in fuel economy for various vehicle models, result in a wide range of fuel costs per mile driven. The range of fuel costs per mile for the alternative fuel and gasoline vehicles in the Federal light-duty evaluation program is shown in Figure 17. For sedans in the program, the average cost per mile for ethanol and methanol is somewhat higher than for gasoline, but for vans, compressed natural gas is competitive with gasoline in average cost per mile. The actual cost per mile for any specific vehicle is affected by factors such as the driving cycle of the vehicle, the driving style of the operator, and the local price of fuel.

Comparative Oil Costs

Oil cost is a function of both price and the frequency of oil change. Because automobile manufacturers recommend more frequent oil changes for alcohol-fuel vehicles, the oil cost for these vehicles is generally higher than for gasoline vehicles. Typical oil costs are about $0.013 per mile for alcohol-fuel vehicles, and $0.007 cents per mile for gasoline vehicles. The manufacturer-recommended oil-change schedule is the same for vehicles fueled with compressed natural gas and those fueled with gasoline. Therefore, assuming comparability of prices, these vehicles would realize similar oil costs. All vehicles in the Federal light-duty evaluation program had their oil changed according to the manufacturers' recommended oil-change-interval schedules.

Comparative Maintenance Costs

Most maintenance on General Services Administration vehicles is performed under warranty at no cost to the fleet operator (except for lost time in service). Therefore, data on the actual cost of maintenance, and a summary of average maintenance costs per mile, are not available. In general, maintenance costs are expected to be marginally higher for alternative fuel vehicles than for gasoline vehicles. One reason is that parts cost more for models that are in relatively limited production (which is the case for most alternative fuel vehicles). Also, experience with the vehicles in the Federal light-duty evaluation program indicates that some maintenance costs are unique to alternative fuel vehicles. Although fuel pump and injector problems were common for the early models, they are decreasing as manufacturers gain experience and improve the overall vehicle design.

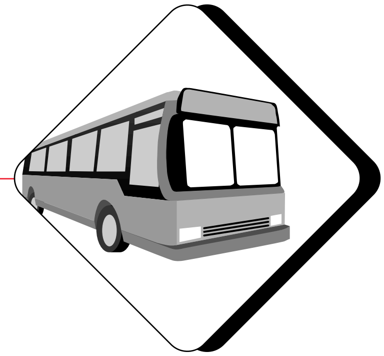
As previously noted, analysis of information available to date indicates that the number of unscheduled repairs (as opposed to the cost of repairs) on alternative fuel vehicles decreases with each new model year. This evidence, along with growing experience, increases the confidence that in the long term, average maintenance costs for alternative fuel vehicles will approach those of standard gasoline vehicles.

Summary

Sustained progress is being made toward accomplishing the goals of the Federal light-duty vehicle demonstration program. A substantial body of evidence pertaining to emissions, performance and reliability, fuel economy, and costs has been accumulated.

The information collected to date suggests that original equipment, light-duty alternative fuel vehicles emit fewer pollutants into the atmosphere than, and achieve fuel economy results similar to, their gasoline counterparts. The available evidence also points to extended improvements in light-duty alternative fuel vehicle technology. In particular, enhancements to vehicle designs have led to performance and reliability levels approaching those of conventional gasoline vehicles. Finally, the most current information indicates that the overall costs of owning and operating light-duty alternative fuel vehicles continue to exceed the corresponding costs of owning and operating light-duty gasoline vehicles. This difference, however, is expected to diminish as the market demand for alternative fuel vehicles increases.

Transit Buses



Overview

The Federal transit bus evaluation program (section 400 CC of the Energy Policy and Conservation Act) is designed to provide a comprehensive study of the alternative fuels currently used by the transit bus industry. The program focuses on the emissions levels, fuel economy, reliability, and operating costs of the various fuels and engines.

To obtain the detailed information necessary to make valid comparisons, transit agencies that meet the following criteria have been selected to participate in the program:

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

The following eight metropolitan areas were selected for program participation: Houston, Texas; Miami, Florida; Minneapolis, Minnesota; New York, New York; Peoria, Illinois, St. Louis, Missouri; Tacoma, Washington; and Portland, Oregon (see Figure 18). Transit buses used by the transit agencies of these eight municipalities are being operated, and are undergoing a number of tests, on four different alternative fuels—compressed natural gas, liquefied natural gas, methanol, and ethanol—plus B20, a blend of 20 percent biodiesel and 80 percent conventional diesel fuel (B20 is not considered by the Department of Energy to be an alternative fuel under the Act). Figure 19 shows the numbers and percentages of transit buses in the program operating on each fuel type.

The goal of the Federal transit bus evaluation program is to test emissions and collect operating data on a minimum of five transit buses at each location running on a single alternative fuel, as well as a minimum of five standard transit

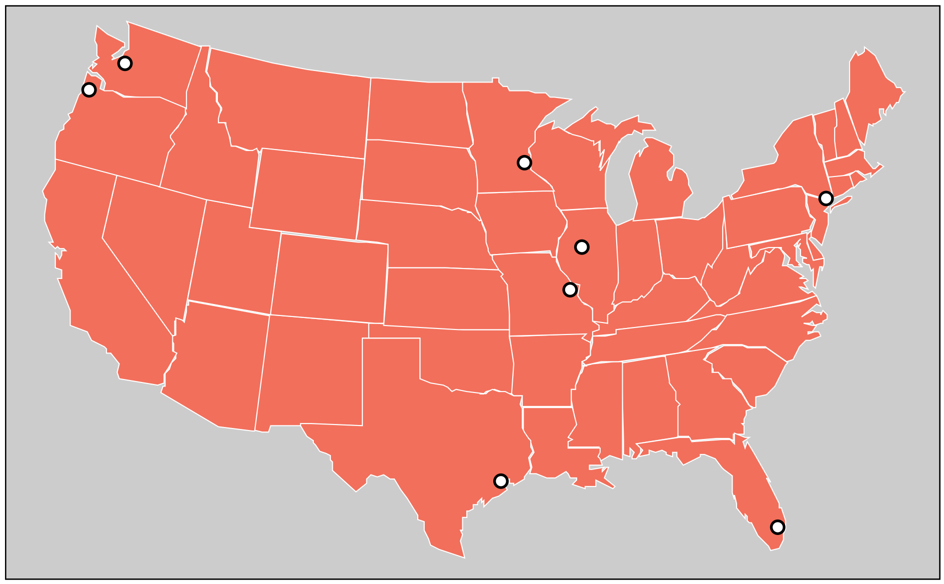


Figure 18. The eight metropolitan areas that currently participate in the Federal transit bus evaluation program

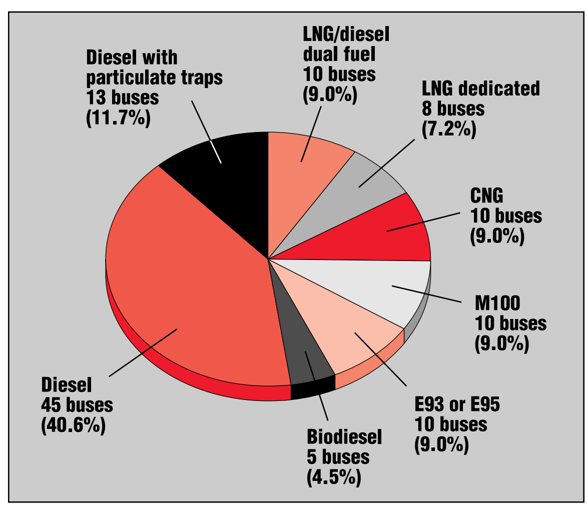


Figure 19. The number of transit buses in the program operating on each type of fuel

Photo courtesy of West Virginia University/PIX 03319

West Virginia University's transportable chassis dynamometer

buses running on diesel (the control group). In St. Louis, however, five transit buses operating on B20, a biodiesel blend not considered to be an alternative fuel under the Act, and five transit buses operating on standard diesel are being tracked. Table A-2 in the Appendix provides a summary of all the transit buses at the various sites included in the evaluation program.

This colorful transit bus runs on ethanol fuel in the Peoria area.

Photo courtesy of Greater Peoria Mass Transit District/PIX 03320

With regard to data collection and dissemination, a subcontractor obtains information on maintenance, fuel usage, added oil, and various costs from each transit agency. The subcontractor then processes the data, converts them into a standard form, submits them to the U.S. Department of Energy's Alternative Fuels Data Center at the National Renewable Energy Laboratory, and analyzes the results. The Alternative Fuels Data Center then makes the information available to the public through reports, as well as a series of database queries, all designed to present the information in a concise and logical format.

In addition to the operating data collected on the demonstration transit buses at each site, West Virginia University personnel visit each location to conduct emissions tests on the transit buses using the university's transportable chassis dynamometer (shown in the photo to the left; discussion follows below). These data are also processed and forwarded to the Alternative Fuels Data Center for analysis, retention, and dissemination.

The alternative fuel engines included in the transit bus evaluation program are:

- Detroit Diesel 6V92TA methanol engine
- Detroit Diesel 6V92TA ethanol engine
- Detroit Diesel 6V92TA pilot ignition natural gas engine
- Cummins L10G natural gas engine.

The biodiesel transit buses use B20 in an unaltered Detroit Diesel 6V92TA engine. Each engine has a horsepower rating between 240 and 280. All transit buses are 35-foot or 40-foot models manufactured by Mercedes, Flxible, Gillig, TMC, or 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 validate the concept of operation on alternative fuels, and to identify areas of improvement. Since that time, both companies have enhanced their engines and emissions control systems.

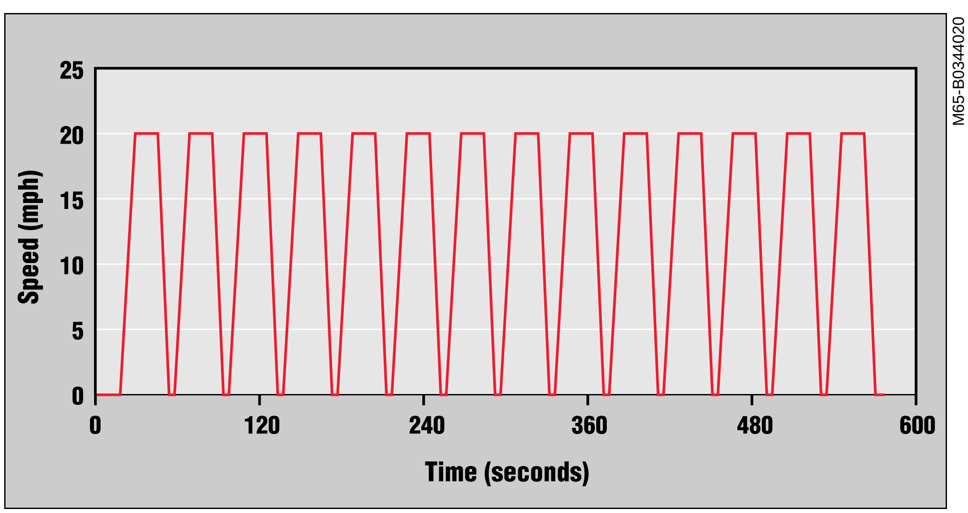
Emissions

With funding from the U.S. Department of Energy, 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 portability of this chassis dynamometer allows a large number of emissions tests on transit buses and heavy-duty vehicles to be conducted on site around the country. Before the unit was built, other options were considered, such as transporting vehicles to stationary dynamometers, or removing engines and transporting them to facilities. Both options were rejected because of expense and vehicle downtime.

West Virginia University maintains an up-to-date description of the dynamometer's design and operating characteristics, as well as all details of the emissions test procedures. Typically, this transportable chassis dynamometer is set up on the grounds of the test fleet or local transit agency, and heavy-duty trucks or transit buses are tested using the fuel resident 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. To test emissions on the transit buses in the Federal evaluation program, West Virginia University uses the standard Central Business District test cycle, a driving cycle devised to simulate speeds, loads, and conditions experienced by transit buses during a typical route through a city's Central Business District (see Figure 20).

During 1995, West Virginia University personnel traveled to transit agency facilities in New York City, Miami, Peoria, St. Louis, Minneapolis, Tacoma, and Portland to test transit buses included in the Federal evaluation program.

Figure 20. Central Business District chassis dynamometer driving cycle



Summaries of the results from emissions tests performed on 24 compressed natural gas, 10 methanol, 10 ethanol, and comparable numbers of diesel buses (the control group) are provided in the sections below.

Comparing exhaust emissions levels between heavy-duty vehicle technologies is a complex and evolving matter. Both the engine certification and chassis dynamometer testing have shown that alternative fuels have the potential to substantially reduce emissions levels, but emissions also may vary widely depending on engine technology and vehicle condition. Test results from the most recent offerings of compressed natural gas and alcohol fuel engines, suggest that emissions can be reduced significantly. Although efforts are continually being made to include the latest technologies available in the Federal evaluation program, many transit buses tested over the past several years represent early versions of alternative fuel engines that were originally part of either a manufacturer's demonstration project, or were deployed to help develop alternative fuel technology. Each manufacturer has updated its engine designs based on results from these studies.

In general, the results of emissions testing vehicles in the Federal transit bus evaluation program are highly variable. Early testing showed that some of the alternative fuel transit buses exhibited high levels of hydrocarbons and carbon monoxide. In cooperation with the engine manufacturers, it was discovered that many of these vehicles were either improperly tuned or had problems with fuel injectors, catalytic converters, or mixing valves. Recently, dramatic reductions in hydrocarbons and carbon monoxide emissions were achieved on compressed natural gas buses in Miami and Tacoma after manufacturer representatives performed problem diagnosis on the high-emitting vehicles and corrected the problems they discovered.

Table 1. U. S. Environmental Protection Agency Heavy-Duty Engine Emissions Certification Standards (in grams per brake horsepower-hour) for Urban Transit Buses

	CO	NO_X	HC	PM
1991–92	15.5	5.0	1.3	0.25
1993	15.5	5.0	1.3	0.10
1994–95	15.5	5.0	1.3	0.07
1996–97	15.5	5.0	1.3	0.05
1998	15.5	4.0	1.3	0.05

The variability in hydrocarbons and carbon monoxide notwithstanding, alternative fuel transit buses appear to be particularly well suited to reducing emissions of particulate matter and oxides of nitrogen. This feature is quite important, as Federal emissions standards for these components are becoming more stringent (see Table 1). Representatives from the heavy-duty engine manufacturers, the U.S. Environmental Protection Agency, and the California Air Resources Board have signed a statement of principles aimed at reducing emissions of oxides of nitrogen to

2.0 grams per brake horsepower-hour by the year 2004, while not lowering the standards for particulate matter.

West Virginia University's emissions testing activities have helped to underscore two very important points. First, by participating in demonstration programs, transit agencies can play an important role in developing technologies that will help to improve air quality. Second, the diagnosis and repair of high emitters have shown that even though the use of alternative fuels may reduce emissions, engine technology and proper vehicle maintenance are also crucial factors.

Compressed Natural Gas

Most compressed natural gas transit buses tested so far have been early versions of the Cummins L10G engine that were not certified by the Environmental Protection Agency. Cummins has since made several improvements to enhance engine performance and reduce emissions levels. Later versions of this engine have been certified by the California Air Resources Board. Several L10G engines used in New York City transit buses were upgraded to the certified configuration and tested in 1994.

For various exhaust constituents, Figure 21 shows the average, minimum, and maximum emissions measured on transit buses equipped with Cummins L10G engines. A comparison is shown between engines fueled with compressed natural gas and those fueled with diesel. Although the data are somewhat scattered, several general conclusions can be drawn. The most obvious result is that emissions of particulate matter are reduced to nearly zero in engines fueled with compressed natural gas. This is an important and attractive feature of this fuel that reduces the amount of black smoke emanating from city transit buses. Figure 21 also shows that transit buses equipped with the Cummins L10G compressed natural gas engines certified by the California Air Resources Board (CNG 260) exhibit lower carbon monoxide and oxides of nitrogen emissions, on average, than either the original compressed natural gas transit buses (CNG 240) or their diesel counterparts. Average total hydrocarbon emissions from the compressed natural gas transit buses are higher than those for diesel transit sit buses. However, total hydrocarbon emissions from compressed

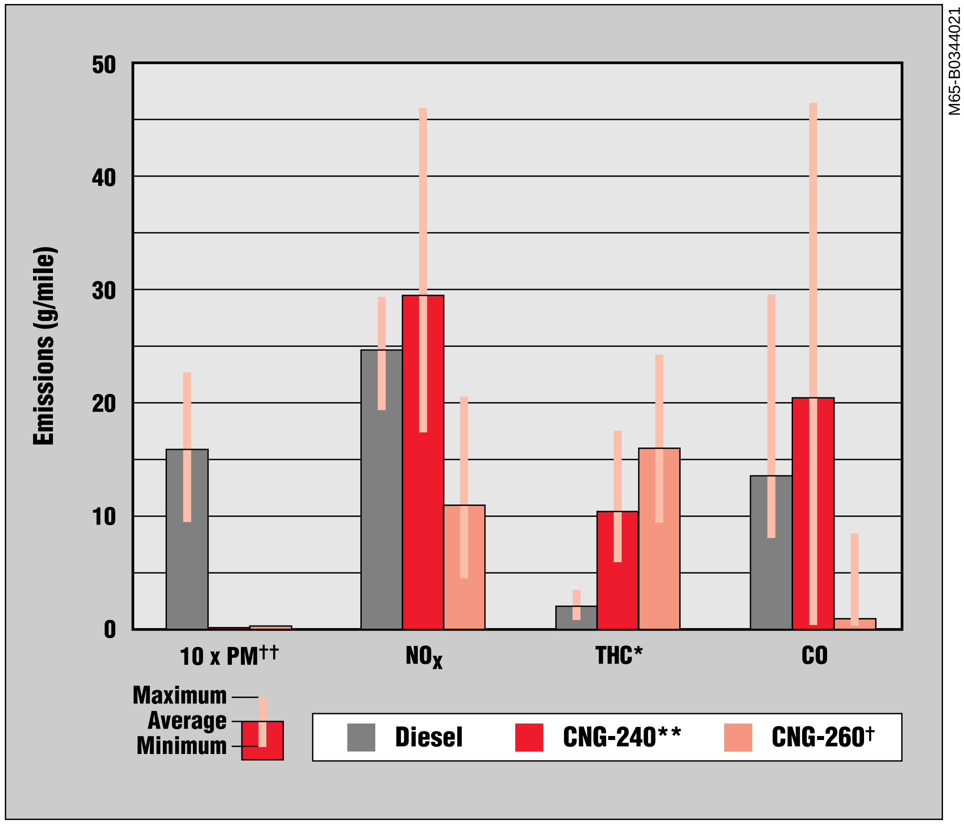


Figure 21. Compressed natural gas versus diesel transit bus emissions (Cummins L10G engines)

* Total hydrocarbons.
** Early production engines, not certified by California Air Resources Board.
† Certified by California Air Resources Board.
†† Particulate matter values were magnified 10 times to show results on the same scale.

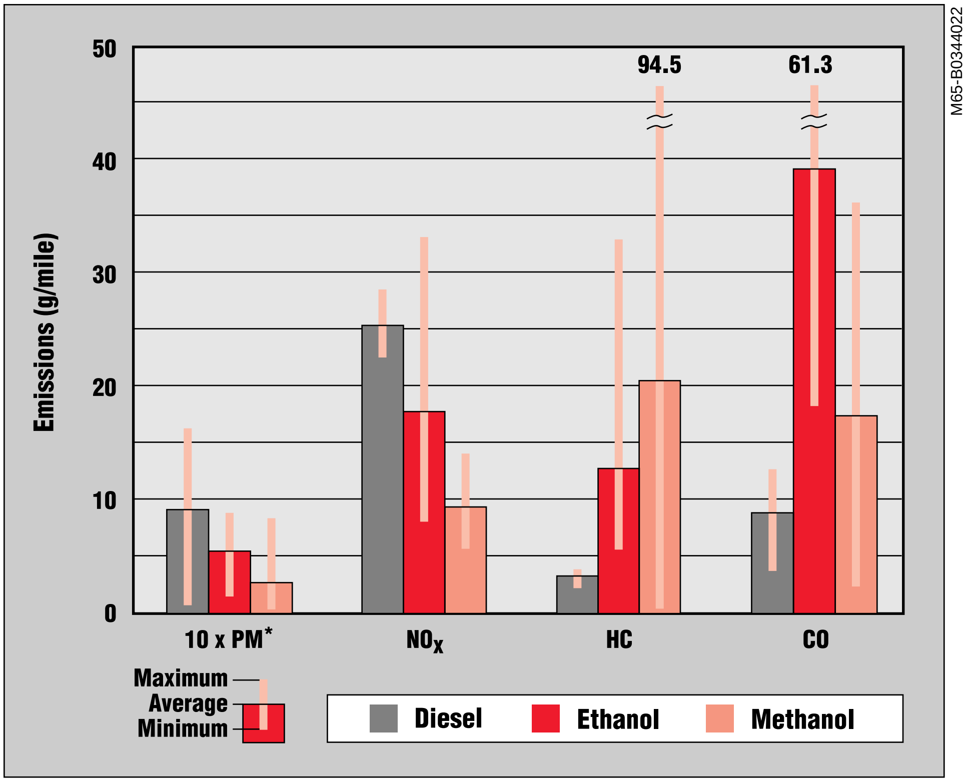


Figure 22. Alcohol versus diesel transit bus emissions (Detroit Diesel Corporation 6V92 engines)

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

natural gas vehicles typically comprise 90 percent to 95 percent methane.

Environmental Protection Agency and California Air Resources Board regulations are written in terms of non-methane hydrocarbons, because methane is considered to be non-reactive in the atmosphere (meaning that it does not contribute to the formation of photochemical smog). However, methane is a potent greenhouse gas—far more active than carbon dioxide. Non-methane hydrocarbon emissions from the compressed natural gas transit buses were not measured directly, but they can be projected to be at similar or lower levels than those for transit diesel buses.

Later versions of the Cummins L10G engine (CNG 260) have been optimized for emissions control, and the first tests on the newer engines included in the Federal demonstration program show substantial reductions in the levels of carbon monoxide and oxides of nitrogen.

On the early generation CNG 240 engines that were high emitters, a cooperative effort with the engine manufacturer was recently completed. West Virginia University's transportable chassis dynamometer was used as a diagnostic tool to assist the engine manufacturers in locating problems. With this effort, relatively small adjustments or repairs to the air/fuel mixing valve achieved dramatic reductions in carbon monoxide and oxides of nitrogen.

A key feature of the newest compressed natural gas engines is electronic "feedback" control of the air/fuel ratio, which measures the oxygen content in the exhaust. Plans are being made now to include some of these new-technology engines in the Federal transit bus evaluation program and to test their exhaust emissions output as they are put into service.

Alcohol

The average, minimum, and maximum results from chassis dynamometer emissions tests on ethanol and methanol transit buses powered by Detroit Diesel 6V92TA engines are shown in Figure 22. The results from these alternative fuel transit buses are quite variable, both from one vehicle to another and from one site to another.

On average, transit buses fueled by ethanol and methanol emit particulate matter levels similar to those emitted by otherwise identical diesel transit buses equipped with particulate traps. These same levels are much lower, on average, than the particulate matter levels emitted by diesel transit buses without traps. Although the particulate traps were effective in reducing particulate matter emissions from diesel transit buses, they were eventually removed from the market and from these vehicles because of maintenance and durability problems.

Most of the ethanol, and all of the methanol, transit buses emitted lower levels of oxides of nitrogen than did their diesel counterparts. On the other hand, the alcohol fuel transit buses emitted higher amounts of hydrocarbons and carbon monoxide, on average, than did their diesel counterparts. Newer methanol transit buses with Detroit Diesel 6V92TA engines operating in New York City exhibited consistently lower carbon monoxide and hydrocarbon emissions than either their diesel counterparts, or the older alcohol fuel transit buses.

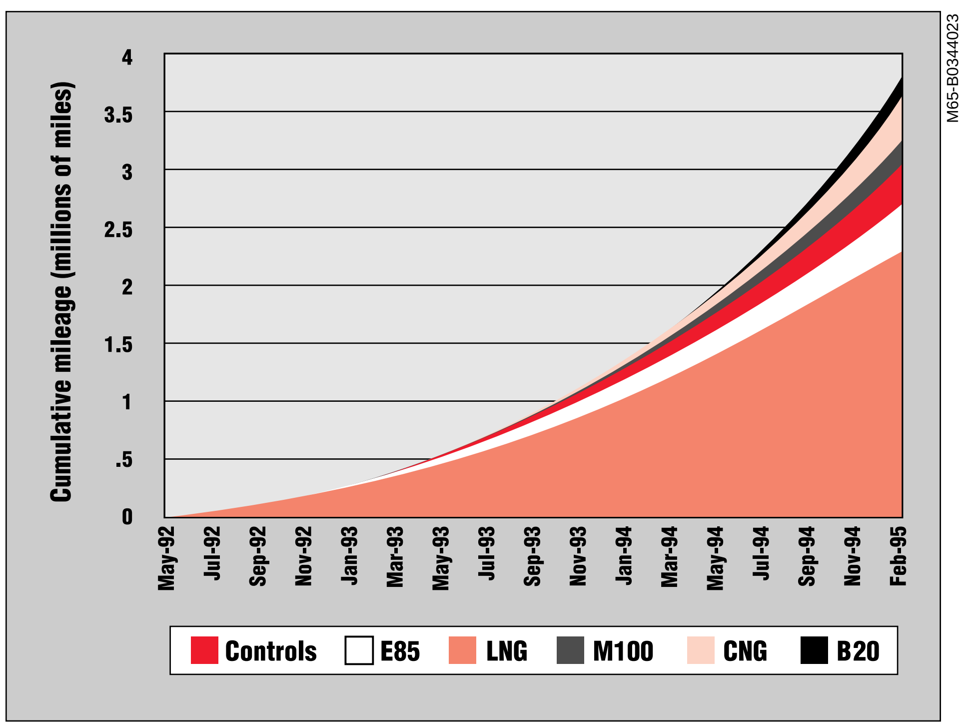
Contrary to some of the test results just noted, certification information on the Detroit Diesel 6V92TA engine indicates emissions reductions should be achieved in all four exhaust constituents (hydrocarbons, carbon monoxide, oxides of nitrogen, and particulate matter). Possible causes (including faulty catalytic converters) for the increased hydrocarbon and carbon monoxide emissions levels recorded for the transit buses in the Federal evaluation program are being investigated. Detroit Diesel has made recent improvements to the fuel injectors, which may also help reduce exhaust emissions levels, and has agreed to work to identify the causes of the higher carbon monoxide and hydrocarbon emissions recorded on the older transit buses in the program.

Miles to Go Before We're Done

The goal of the program is to gather 18 months of data on ten transit buses of each fuel type, with those vehicles being equally divided between two locations. This data collection effort is not complete. Some sites have finished submitting data; others are still doing so. Significant differences between sites often emerge as a result of different experience with the transit buses, different operating conditions, and different reporting procedures. In addition, the manufacturers are constantly updating their engines. Care should therefore be taken in drawing final conclusions about a particular alternative fuel or engine based on the results thus far.

Although Figure 23 shows that almost 4,000,000 total miles have been accumulated on the test vehicles, Figure 24 shows considerable variation in mileage accumulation among the sites. All the current sites should complete their mileage accumulation by mid-1996.

Figure 23. Cumulative mileage on all alternative fuel and control vehicles in the Federal transit bus demonstration program to date



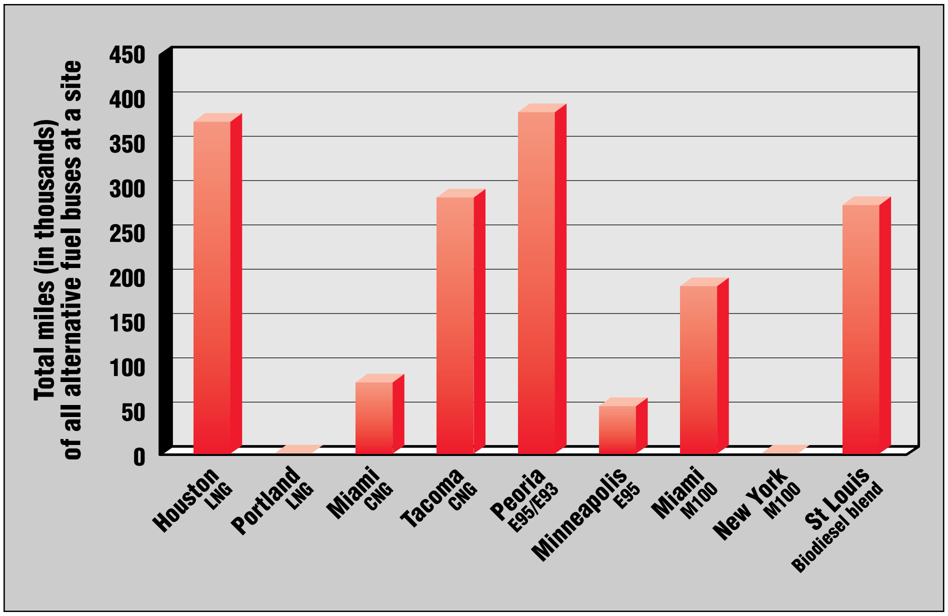
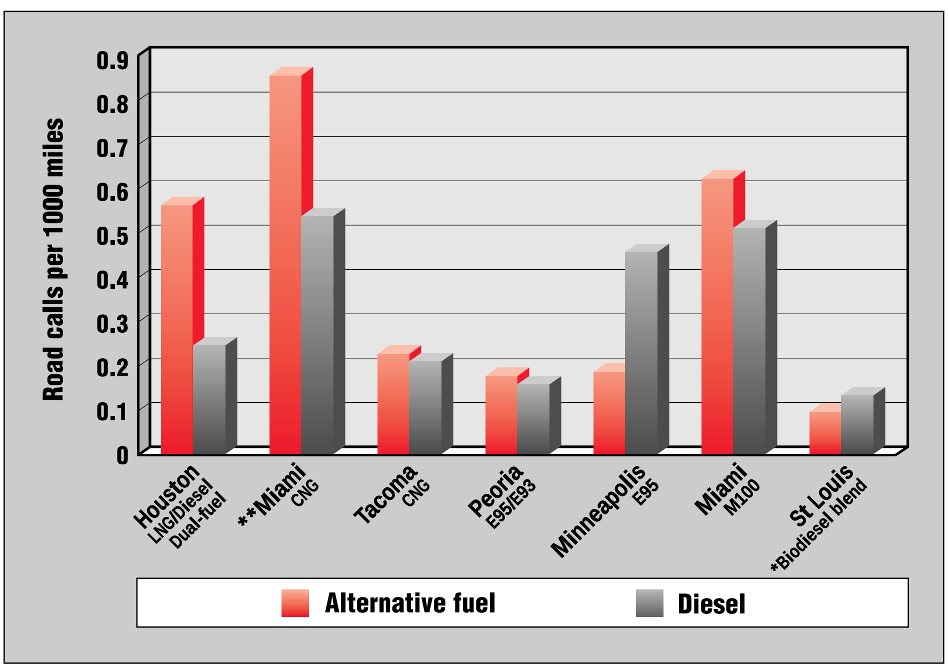


Figure 24. Total mileage on alternative fuel transit buses in the program

Figure 25. Road calls per 1,000 miles of operation

* Biodiesel blends other than B100 are not considered by the U.S. Department of Energy to be alternative fuels at this time.

** Miami alternative fuel transit buses have accumulated relatively low mileage compared to the other CNG site (Tacoma). See Figure 24.



Biodiesel Blend

It was recently discovered that problems had occurred at the St. Louis transit site in mixing the neat biodiesel with the diesel fuel to create B20, the biodiesel blend. As a result, emissions tests were invalidated. Tests will be repeated in 1996 with a new batch of properly blended fuel. Again, the Department of Energy does not consider B20 to be an alternative fuel under the provisions of the Energy Policy Act of 1992.

Performance and Reliability

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

Information on the road calls per 1,000 miles of operation for vehicles in the Federal transit bus evaluation program is shown in Figure 25. A comparison among transit buses operating on different fuels at various locations is provided.

Liquefied Natural Gas

Figure 25 indicates that the dual-fuel transit buses in Houston operating on liquefied natural gas and diesel are experiencing considerably more road calls than their diesel counterparts. The higher count for the dual-fuel vehicles is largely due to running out of fuel or to the system detecting a fuel leak and shutting down the transit bus.

Houston's dual-fuel transit buses experienced more than ten times the rate of road calls for "out of fuel" than did their diesel counterparts, because dual-fuel transit buses have a relatively small diesel 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 transit bus would run out of diesel in a short time because the diesel fuel tank alone is not large enough to run the transit bus independently for long periods of time.

As a check on the difficulties experienced in Houston, an additional location with transit buses running on liquefied natural gas has recently been added to the transit bus evaluation program. The engines in these vehicles are different from those in the Houston vehicles, and as road call information is gathered, comparisons of the two types of engines will be presented.

Other Fuels

In Miami, transit buses running on compressed natural gas experienced a higher rate of road calls per 1,000 miles traveled than did their diesel counterparts. In Tacoma, the rates for the two types of transit buses were about the same. The total mileage accumulated on the Miami compressed natural gas transit buses is relatively limited; therefore, greater weight is given to the Tacoma data. These findings underscore the need to gather information on each alternative fuel at more than one location, and to average data over many miles.

In Peoria, road calls per 1,000 miles for transit buses operating on 95 percent ethanol are comparable to the rate observed for diesel transit buses (the control group) equipped with particulate traps. The Peoria transit buses—both diesel and ethanol—had the lowest road call rates of any vehicles at any location in the Federal transit bus evaluation program.

In Miami, transit buses operating on 100 percent methanol have a somewhat higher road call rate than their diesel counterparts. This difference is primarily due to problems with the fuel systems and engine stalling. Again, however, this information is based on a relatively small mileage accumulation—less than 200,000 miles. A second location—New York (Triboro)—with more transit buses running on 100 percent methanol, was recently added to the Federal evaluation program in hopes of obtaining data over a larger number of miles traveled. Data from New York will be compared to the Miami results as they become available.

Fuel Economy

Fuel economy and fuel costs are very important to transit agencies because these elements represent a significant portion of the total expense of operating a transit bus. Approximately half the total cost (excluding driver wages) of operating a diesel transit bus is directly attributable to fuel economy and fuel cost. In contrast, these items represent more than half the total cost of operating some alternative fuel transit buses.

As in the case of light-duty vehicles, fuel economy for transit buses can be determined in two ways: as direct measurements from engine dynamometer tests, and from actual in-use service. Figure 26 shows the average fuel economy from engine dynamometer tests, as well as a range of in-use fuel economy, for

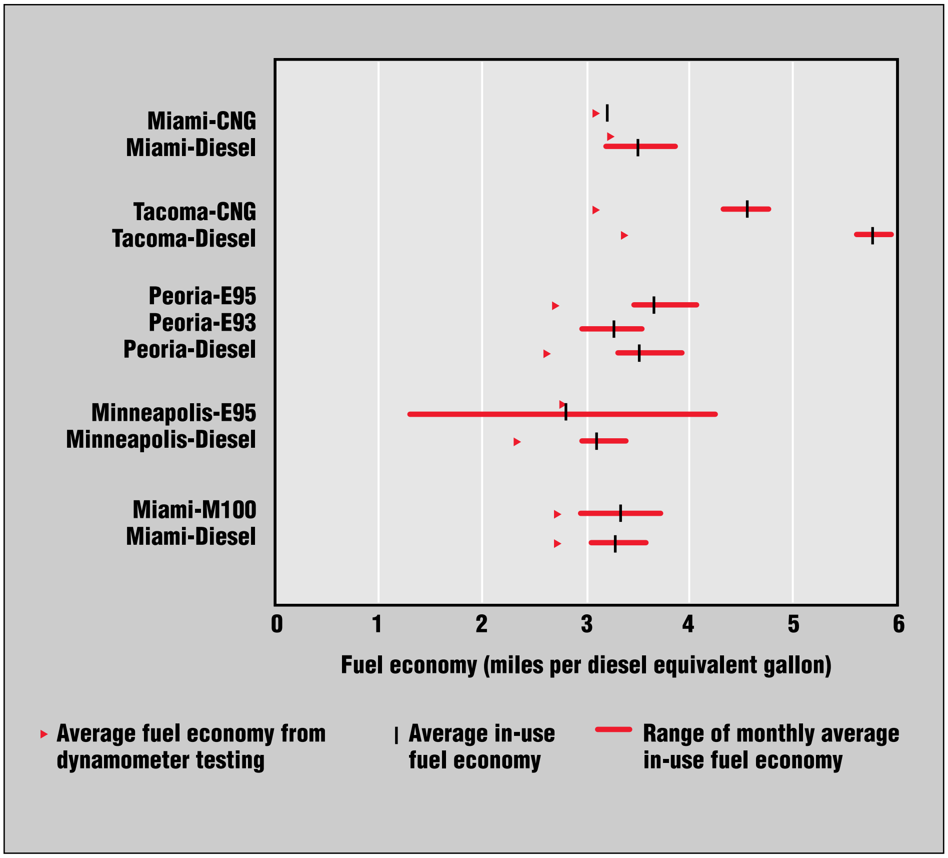


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Figure 26. Average fuel economy for transit buses, expressed as miles per diesel equivalent gallon*

* Information from the Houston LNG transit buses is not shown because only a single point average is available as opposed to the range of values available for other types of buses.

the vehicles included in the Federal transit bus evaluation program. A comparison is made among the various types of fuels used at different program locations. Expressing fuel economy in miles per equivalent gallon of diesel facilitates a direct comparison of the relative energy efficiency of the various alternative fuels.

As illustrated in Figure 26, fuel economy varies between fuels, and from one site to the next. This variability may result from differences in driving cycles among transit bus types and among locations.

On the other hand, the dynamometer results, which were obtained using the Central Business District driving cycle, are relatively constant. This observation partly confirms the above suggestion that variability in the in-use results is due to differences in driving cycle. However, because the dynamometer fuel economy values are consistently below the average in-use values, the Central Business District driving cycle may not be representative of the actual driving cycles of the transit buses in the program.

As a follow-on to the above discussion about the fuel economy achieved by the vehicles in the Federal transit bus evaluation program, additional comments and analytical comparisons can be made. The first have to do with the liquefied natural gas engines in the transit buses operated in Houston. These engines operate on a compression-ignition cycle; that is, diesel is used as a "pilot ignition" source to ignite the natural gas. The average fuel economy for these transit buses was calculated by summing the amount of liquefied natural gas (in diesel equivalent gallons) and diesel burned in the transit buses over time, and dividing that sum by the total miles logged. The resulting number (3.1 miles per diesel equivalent gallon) was approximately 16 percent less than the average fuel economy for the diesel counterparts. The lower fuel economy for liquefied natural gas transit buses may be partly attributed to the extra weight (approximately 860 pounds), but is more likely to be the result of problems with the engine, or with external factors such as driving cycles.

It is interesting to note that, when the dual-fuel transit buses were operating in their "backup" mode of diesel only, the fuel economy was within 4 percent of that of the diesel transit buses (the control group). This indicates that the extra weight of the dual-fuel transit buses is not the major deterrent to fuel economy.

A second point of note has to do with the compressed natural gas engines in transit buses operated at Miami and Tacoma. These are spark-ignited throttle engines. The diesel engines, in contrast, are unthrottled compression-ignition engines. When a diesel compression-ignition engine is redesigned into a spark-ignition engine running on compressed natural gas (as is the case with all the compressed natural gas engines in the Federal evaluation program transit buses), there is an inherent reduction in efficiency (fuel economy) 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 exhibits minimal pumping losses, whereas a spark-ignited engine with a throttle realizes 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 deterrent to fuel economy in the compressed natural gas transit buses is their weight—about 3,900 pounds more than otherwise identical diesel transit buses. This weight penalty, which is largely attributable to the fuel tanks, results in about a 15 percent increase in the curb weight of a transit bus (the standard diesel transit buses have a curb weight of approximately 27,000 pounds).

Because all the above factors are expected to adversely affect energy efficiency, the reported difference in fuel economy between the compressed natural gas and diesel transit buses is not surprising. The average fuel economy of the compressed natural gas transit buses from dynamometer tests is about 10 percent to 20 percent lower than the corresponding average fuel economy for their diesel counterparts.

Third, with regard to fuel economy of alcohol transit buses, there are also adverse weight factors to consider. The alcohol option results in a weight penalty of between 1,000 and 1,500 pounds, depending on fuel tank capacity. In specific regard to the alcohol transit buses operated in Miami, another 1,200 pounds is attributed to options and specifications unrelated to the engine or fuel system. Alcohol transit buses also have very high compression ratios (more than 20 to 1), which also tend to lower fuel economy because of friction losses (for example, piston side loading). Consequently, even before data began to be collected on these transit buses, they were expected to exhibit lower fuel economy, on average, than their diesel counterparts.

Despite these considerations, the results to date indicate that the alcohol fuel transit buses at all the sites are performing very well, delivering fuel economy comparable to that of their diesel counterparts. A possible explanation is that the weight and compression ratio penalties may not be as significant as the pumping losses caused by throttling. The 95 percent ethanol and the 100 percent methanol engines at Peoria, Minneapolis, and Miami are powered by unthrottled compression-ignition engines, so they do not suffer from the same pumping loss penalties as the compressed natural gas buses. Also, the standard diesel transit buses (control group) at Peoria are equipped with particulate traps, which are known to lower fuel economy slightly.

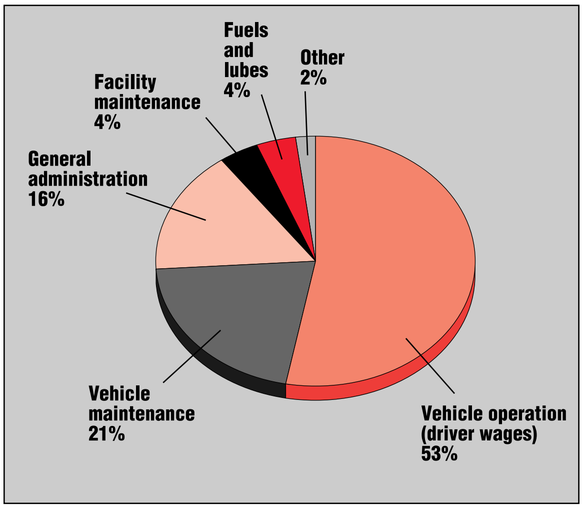


Figure 27. Total operating costs for a large transit agency

In summary, most fuel economy results to date are in line with expectations, with the possible exceptions of the numbers reported for liquefied natural gas dual-fuel engines. Data collection efforts are continuing, and updates to the profiles noted above are anticipated.

Cost

The incremental costs associated with operating alternative fuel transit buses can be aggregated into two categories: increased capital outlays and increased operating expenses.

Increased capital outlays are attributable to the additional costs (if any) of acquiring alternative fuel transit buses and modifying facilities. Increased operating expenses are due to a larger number of factors. Figure 27 shows a breakdown of the total operating costs for a typical large transit agency such as the ones participating in the Federal transit bus evaluation program. Driver labor costs represent more than half of the total. Operating components likely to be affected by the introduction of alternative fuel transit buses are vehicle maintenance, facility maintenance, and fuels and lubricants availability and cost. Together, however, these components represent only about a third of the total operating expense.

Comparative Facility Costs

Because transit buses are centrally stored and refueled at facilities owned and operated by transit agencies, the capital and operating costs associated with any changes to those facilities to accommodate alternative fuel transit buses become an important part of the total cost of doing business. The price for new facilities, or modifications to existing facilities, varies widely, even when only one type of alternative fuel vehicle is involved. The cost is likely to be highest when compressed natural gas or liquefied natural gas is the alternative fuel of choice. The necessary changes can include installation of new refueling stations, as well as installation of monitoring and ventilation equipment. Construction and equipment installation costs are affected, in turn, by the size of the agency involved, and by the state and local building codes. Some representative incremental capital costs are shown in Table 2.

Table 2. Incremental Facility Costs for a Fleet of 160 Alternative Fuel Transit Buses (In millions of 1994 dollars)

	LNG	CNG	Alcohols*	Propane**	Biodiesel blend***
Fueling Facility	$0.9	$1.5	$0.1	$0.2	NC
Maintenance Facility	$1.2	$1.1	NC	NC**	NC
Bus Storage Facility	$1.4	$1.2	NC	NC**	NC
Total	$3.5	$3.8	$0.1	$0.2	NC

NC No change if facility is certified for gasoline

* Methanol and ethanol

** The installation of propane gas detection systems in areas where propane-fueled vehicles are parked or maintained may be required by local authorities or considered to be good practice by facility design engineers. Increased ventilation to handle possible propane releases may also be included in the facility design. Often, the operation of such increased ventilation is tied to the gas detection system.

*** Only neat biodiesel (B100) is currently considered by the Department of Energy to be an alternative fuel under the provisions of the Act.

Source: *Battelle Memorial Institute; based on previous reports completed for the Federal Transit Administration and the American Trucking Association by Battelle Memorial Institute and Gannett Fleming.*

Incremental Acquisition Costs

At the time of this writing, transit buses operating on alternative fuels are more expensive to purchase than those operating on diesel. Higher engine costs represent a significant portion of the higher purchase price. Because alternative fuel engines are in relatively limited production, the manufacturers charge $25,000 to $30,000 more for them than for standard diesel engines. As their production volumes increase, though, the cost of alternative fuel engines will begin to approach those of their diesel counterparts. Yet it is unclear whether the price of alternative fuel engines for transit buses will ever equal that of comparable diesel engines. Transit buses operating on biodiesel blends (which are not considered by the Department of Energy to be alternative fuels under the provisions of the Act) are the exception to this rule, because they are automatically outfitted with conventional diesel engines (hence, there is no incremental acquisition cost).

In addition to being equipped with more expensive engines, the fuel tanks on alternative fuel transit buses cost more than their conventional diesel counterparts. The incremental amount can range 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 add no expense to the cost of buses operating on biodiesel blends.

Comparative Fuel Costs

In 1995, the price paid for a gallon of diesel fuel by the transit agencies with vehicles in the Federal transit bus demonstration program ranged from about $0.47 to about $0.65. The corresponding price for an alternative fuel on an equivalent-gallon-of-diesel basis was even more variable, depending on the fuel of interest. With a range of

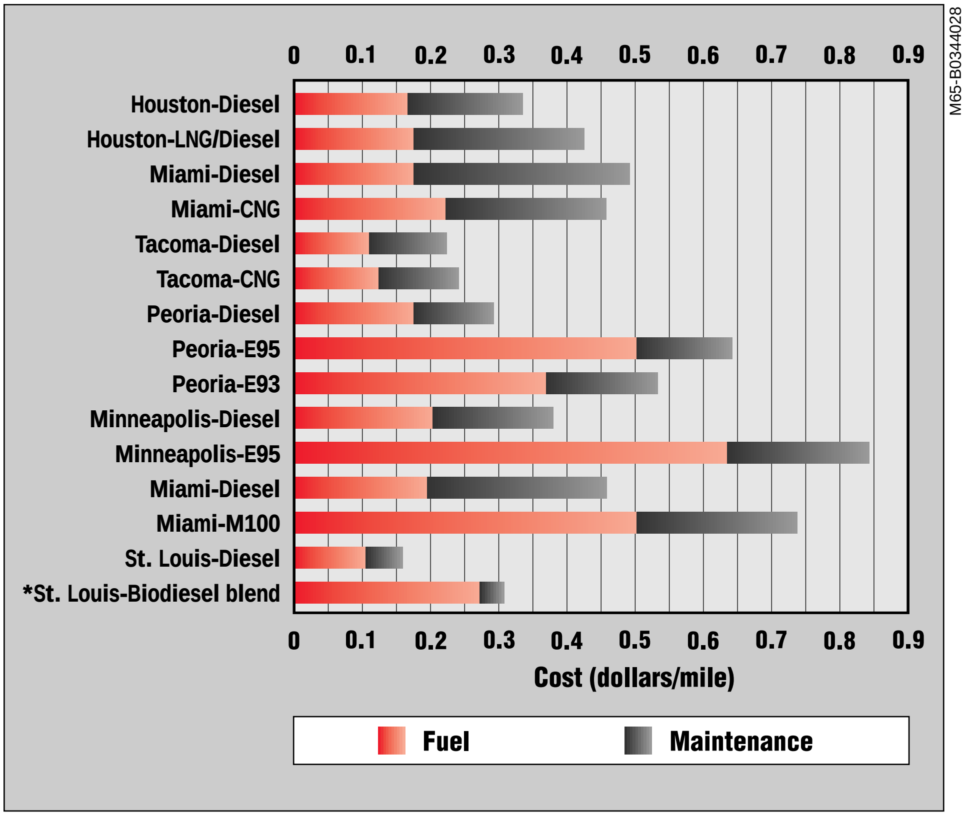


Figure 28. Transit bus fuel and maintenance costs per mile traveled (Note: Maintenance costs for the transit buses at St. Louis include only costs related to the engine/fuel system.)

* Biodiesel blends other than B100 are not currently considered by the U.S. Department of Energy to be alternative fuels

$0.55 to $0.69 per diesel equivalent gallon, compressed natural gas was the cheapest. This price excludes the cost of electricity needed to compress the fuel.

One hundred percent methanol cost $1.72 per diesel equivalent gallon. The price paid for 95 percent ethanol was $1.83 per diesel equivalent gallon, making it the most costly of the fuels used.

Some additional variations were noted on a regional basis. 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 $0.43 per gallon “blenders’ credit,” which lowered its fuel cost to $1.21 per diesel equivalent gallon. B20, the biodiesel blend used in Missouri (not considered by the Department of Energy to be an alternative fuel at this time), cost about $1.00 per diesel equivalent gallon, and the liquefied natural gas and diesel combination used in Houston cost about $0.80 per diesel equivalent gallon.

In general, the prices of alternative fuels are more variable and more expensive than those of diesel, not only from one region to another, but also from one period of time to another.

Comparative Maintenance Costs

Maintenance costs are continually being tracked for all the vehicles in the Federal transit bus evaluation program. Copies of all the work orders, as well as lists of the parts replaced, are received from the transit agency involved. This information is coded by the type of work performed (for example, scheduled maintenance, unscheduled maintenance, road calls, and configuration changes to the buses), and various vehicle subsystems are identified (for example, engine type and fuel system).

A few words of caution are necessary about using the maintenance data. As more miles are logged on the transit buses, a better maintenance profile emerges. Maintenance records of low-mileage vehicles cannot be extrapolated. Also, comparisons of maintenance records from different agencies should be avoided, because of differences in the way in which maintenance incidences are defined and recorded. Finally, the maintenance cost data do not include warranty repair work performed on the transit buses because the agencies do not bear the cost of this activity.

Some general comments can be made regarding the cost of maintaining vehicles in the Federal transit bus evaluation program. According to the data available, maintenance costs for the Houston transit buses operating on a combination of liquefied natural gas and diesel are considerably higher than those of their diesel counterparts. This is partly due to difficulties with the gas injectors and with contaminants in the fuel. Fuel system leaks are also a source of concern. However, as of this writing, all problems are being rectified by the engine manufacturers and by Houston Metro. The maintenance costs of transit buses operating on all the other alternative fuels at all other locations are comparable to those of their diesel counterparts.

Cost per Mile Traveled

Figure 28 shows the fuel and maintenance costs per mile traveled for the vehicles in the transit bus demonstration program. The fuel cost per mile was calculated using average in-use fuel economy and the actual fuel cost paid by the transit agencies. For transit buses operating on compressed natural gas, the fuel and maintenance costs per mile are about the same as those for transit buses operating on diesel.

However, for transit buses operating on an alcohol fuel or B20 (a biodiesel blend that is not, at this time, considered by the Department of Energy to be an alternative fuel), the same costs are up to twice as high as those for transit buses operating on diesel. The fuel and maintenance costs for transit buses operating on liquefied natural gas/diesel are about 25 percent higher than for their diesel counterparts.

Summary

Transit buses potentially represent one of the best applications for alternative fuels, and the transit bus data collection efforts have been some of the most successful in the Federal alternative fuel evaluation programs. The transit bus evaluation program has accumulated a respected body of evidence on the emissions, performance and reliability, fuel economy, and cost of alternative fuel buses. This information is leading to the continued development and proliferation of this technology.

Depending on the alternative fuel, the emissions results for the transit buses in the program are still highly variable. However, a few general conclusions can be drawn. All the alternative fuels did emit decreased levels of particulate matter, which has been linked to detrimental human health effects. With compressed natural gas, particulate matter emissions are almost zero. Compressed natural gas vehicles have also shown the potential to have very low carbon monoxide, non-methane hydrocarbons, and, to a lesser extent, nitrogen oxide emissions. However, the level of technology of the engine and the maintenance on the engine have been shown to be equally important factors in reducing exhaust emissions.

In most cases, the reliability of the alternative fuel transit buses in the program proved to be similar to the reliability of the diesel control transit buses. This is a positive sign, considering the relative immaturity of this market versus the diesel market. The exceptions are the liquefied natural gas dual-fuel transit buses in Houston (the engines in these buses are no longer in production), and the compressed natural gas transit buses in Miami, which have very low mileage. Similar compressed natural gas transit buses in Tacoma have much higher mileage, and have proven reliable.

At this time, no fuel has been shown to have both a low up-front capital cost and a low operating cost. The alcohol and B20 (a low-level biodiesel blend that the Department of Energy does not consider to be an alternative fuel under the provisions of the Act) transit buses have a low to moderate up-front cost, but higher operating costs resulting from the relatively high fuel prices. The compressed natural gas transit buses, on the other hand, have a high up-front cost for acquisition and infrastructure, but their operating costs are similar to those of diesel transit buses. As time goes on and production volumes increase, the price of alternative fuel transit buses should decrease, although it is unclear how close they will come to the cost of a diesel transit bus.

Heavy-Duty Vehicles

Overview

The Federal heavy-duty demonstration program (section 400 BB of the Energy Policy and Conservation Act) includes two types of vehicles: medium-size commercial delivery vans and large trucks (such as tractor trailers and garbage packers). In total, some 170 delivery vans and large trucks are included in the program, and Figure 29 identifies their service locations. Actual vehicle descriptions and their service functions are listed in Table A-3 in the Appendix.

Delivery vans in two commercial delivery fleets are included: the Federal Express fleet and the United Parcel Service fleet. The Federal Express vehicles are evaluated in the CleanFleet project, which is coordinated by Battelle Memorial Institute.

The CleanFleet project has been completed, and the final report is being prepared. Delivery vans operating on several alternative fuels were tracked, including those running on compressed natural gas, propane, and 85 percent methanol, as well as some standard reformulated gasoline vehicles (the control group). The update provided below summarizes the findings available to date from this study.

The United Parcel Service project covers only delivery vans operating on compressed natural gas. Some standard reformulated gasoline vans were also tracked for comparison purposes (the control group). Because large trucks are very expensive to acquire and operate, only a limited number of these vehicles are being tracked in the Federal demonstration program. In addition, because there are so few emissions-certified production engines available for large trucks that operate on alternative fuels, most (but not all) of the vehicles currently included in the program are powered by pre-production field-test engines. In contrast, the transit bus evaluation program includes only emission-certified production engines. These demonstrations serve the dual purpose of allowing the technology to be refined, while demonstrating its viability.

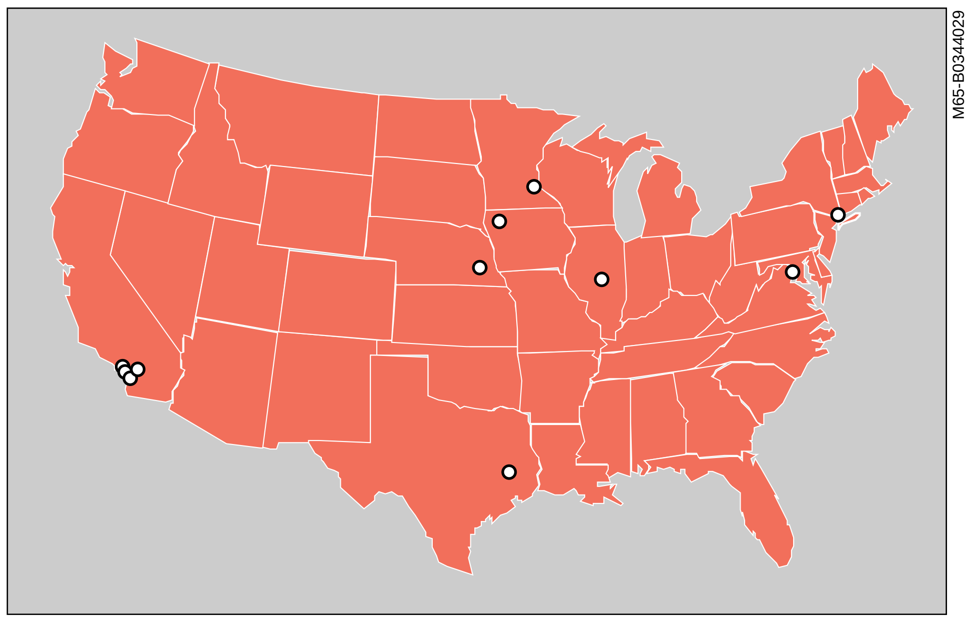


Figure 29. Locations of heavy-duty vehicles in the Federal demonstration program

Heavy-Duty Alternative Fuel Engine Availability

Several original equipment manufacturers 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.

Production

Manufacturer	Model	Fuel	Horsepower Range	Vocations
Detroit Diesel	6V92	E95	250-275	Bus, heavy truck
Detroit Diesel	6V92	M100	250-275	Bus, heavy truck
Detroit Diesel	Series 50	Natural gas	250-275	Bus, garbage packer
Detroit Diesel	Series 30	Natural gas	210	Medium truck
Cummins	B5.9	Natural gas	195	Medium truck, school bus
Cummins	L10G	Natural gas	240-260	Bus, heavy truck, garbage packer
Caterpillar	3306	Natural gas	250	Bus, medium truck, garbage packer
Hercules	GTA 5.6	Natural gas	190	Bus, medium truck

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

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

Pre-Production

Manufacturer	Model	Fuel	Horsepower Range	Vocations
Detroit Diesel	Series 60	Natural gas	370-450	Heavy truck
Detroit Diesel	Series 50	Natural gas	300	Heavy truck
Detroit Diesel	Series 50	Propane	250-275	Bus, Heavy truck
Detroit Diesel	Series 40	Natural gas	Unknown	Medium truck, school bus
Cummins	L10G	Natural gas	300	Heavy truck, garbage packer
Cummins	Mll	Natural gas	340	Heavy truck
Cummins	C8.3	Natural gas	250	Bus, medium truck
Caterpillar	3406	Natural gas	350	Heavy truck
Navistar*	T444	Natural gas	210	Medium truck
Mack	E7	Natural gas	300	Heavy truck
John Deere	6081	Natural gas	250	Bus

** Developed jointly with Detroit Diesel Corporation.*
This engine is the same as the DDC Series 30 natural gas engine.

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.

The sidebar at the left highlights the actual alternative fuel engines available for large trucks that are currently in production or pre-production by original equipment manufacturers. All but one of these engines are dedicated to run on natural gas.

To put as many large trucks in the Federal demonstration program as possible, the U.S. Department of Energy has funded approximately half the acquisition and operation costs of those included. The remainder of the funding has been provided by a variety of entities, including state and local government agencies, public utility companies, fuel suppliers, special interest groups (such as the Minnesota Corn Growers and the Iowa Soybean Association), and host fleets. In many cases, two or more organizations have joined forces to provide the non-Federal portion of the funding.

In contrast to the delivery vans, the large trucks included in the program are used in various specialized functions (called "vocations"), such as

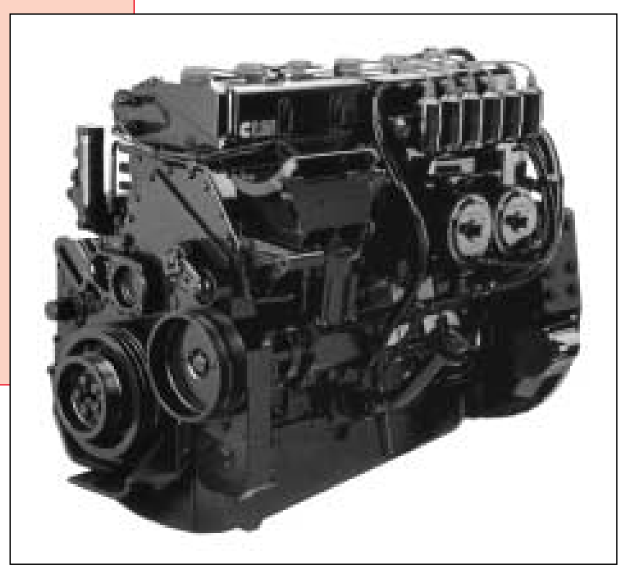


Photo courtesy of Cummins Engine Company/PIX 03318

Cummins L10G engine

picking up refuse or transporting goods over long distances (known as line-haul operation). The driving cycles of large trucks are distinctly different, depending on their vocations. Consequently, an effort has been made to include as many such vocations as possible in the mix of trucks included in this program. Figure 30 shows the current numbers of large trucks by vocation.

For each vehicle (whether van or truck) in this demonstration program, data are being collected on performance, fuel and oil consumption, and any problems encountered. In the case of vehicles powered by pre-production engines, such information is being reported directly to the manufacturers to facilitate technological improvements, which, in turn, will eventually be included in the program.

In addition, vehicles powered by emissions-certified production engines are being emissions tested, with tests performed at regular mileage intervals. Emissions results are being collected on the alternative fuel vehicles and the vehicles operating on conventional fuels, which serve as the control group. Unleaded reformulated gasoline is the conventional fuel for commercial delivery vans; diesel is the standard for large trucks.

Finally, the demonstration program described above is not the only effort under way to foster the use of alternative fuels in heavy-duty applications. The U.S. Department of Energy also manages a grant program that

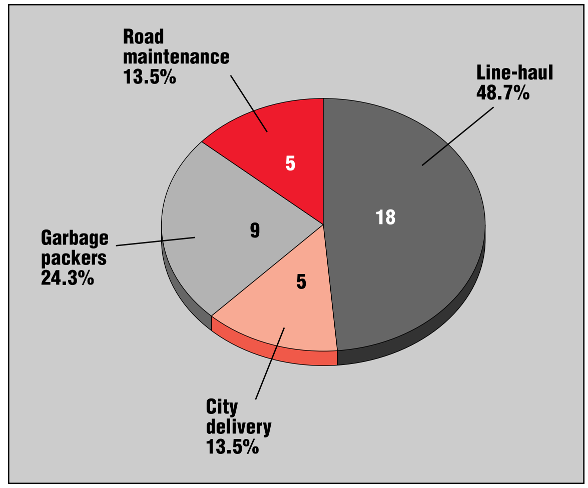


Figure 30. Numbers of large trucks by vocation

Delivering Groceries by Natural Gas

From October 1992 through December 1994, the Vons Grocery Company truck number 9207 drove into El Monte, California, hooked up a trailer loaded with thousands of pounds of groceries, and headed north over Tejon Pass on Interstate 5 to deliver those groceries to Bakersfield. This truck was unique among the 180 Vons trucks based out of the El Monte distribution center—it was powered by compressed natural gas. The Vons natural gas truck operated successfully for 14 months, racking up more than 50,000 kilometers (30,000 miles) of service, and its performance was comparable to that of its diesel-powered cousins.

Caterpillar, Inc., developed a natural gas version of its popular model 3406, 350 horsepower engine for this particular project, and the Vons truck gave it the opportunity to field test its new engine and refine its design. Caterpillar is now using the natural gas truck used in the Vons demonstration to refine the 3406 natural gas engine.

Photo by Warren Gretz, NREL/PIX 03317

The Vons natural gas truck in service

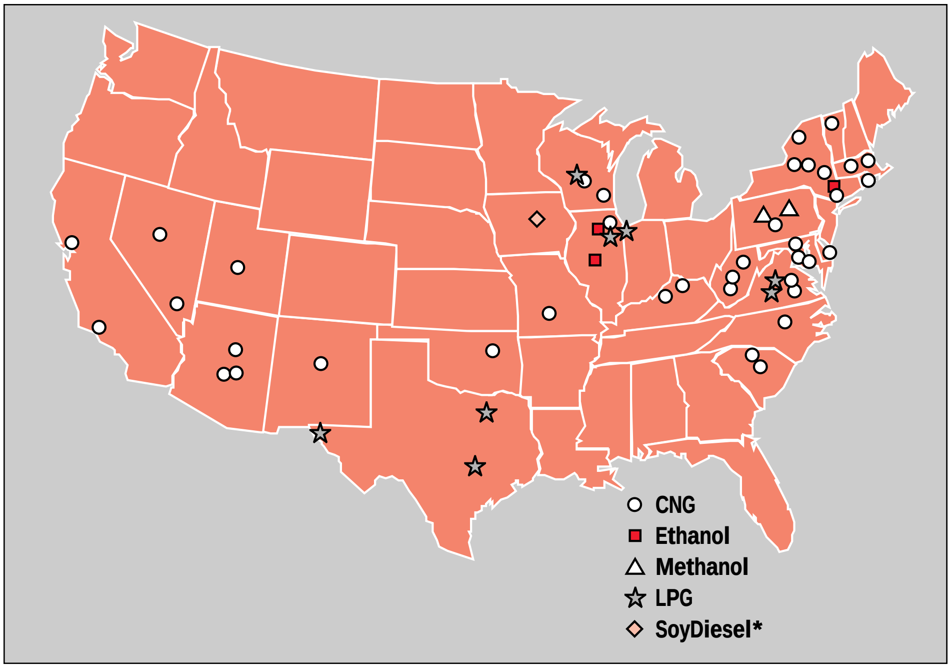


Figure 31. Locations of heavy-duty vehicles in the U.S. Department of Energy grant program

* At this time, soydiesel is not considered by the U.S. Department of Energy to be an alternative fuel

supports states in their purchases of heavy-duty alternative fuel vehicles. The vehicles in the grant program are located across the country, representing vehicle vocations that range from street sweepers to school buses. The locations of these vehicles are shown in Figure 31, with additional details being given in Tables 4 through 7 in the Appendix.

Emissions

As with the transit buses, emissions data were obtained on heavy-duty vehicles using the test equipment and procedures developed by West Virginia University.

Table 3. U.S. Environmental Protection Agency Heavy-Duty Engine Standards (in grams per brake horsepower hour) for Heavy-Duty Trucks

	HC	CO	NO_X	PM
1991–93	1.3	15.5	5.0	0.25
1994–97	1.3	15.5	5.0	0.10
1998	1.3	15.5	4.0	0.10

Large Trucks

During 1995, the 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 ethanol line-haul trucks in Illinois, Hennepin County's ethanol snowplows in Minnesota, and AG Processing Corporation's line-haul trucks operating on a blend of biodiesel and diesel (biodiesel blends other than B100 are not considered by the U.S. Department of Energy to be alternative fuels under the provisions of the Act). A number of diesel control vehicles with the same engine configurations were also tested at each of the sites.

Many of the basic engine configurations deployed in vehicles in the Federal heavy-duty demonstration program, such as the Cummins L10GG compressed natural gas engine and the Detroit Diesel Corporation alcohol 6V92 engines, are the same as those in the vehicles in the Federal transit bus evaluation program.

Although the same engine model may be used for large trucks and transit buses, several important differences still exist. An engine designed for large truck applications will generally have higher horse power and different speed-torque maps, and will be certified under different emissions standards than the same engine model designed for transit bus operation (see Table 3). In addition, many of the large heavy-duty trucks in the program have manual transmissions and are driven

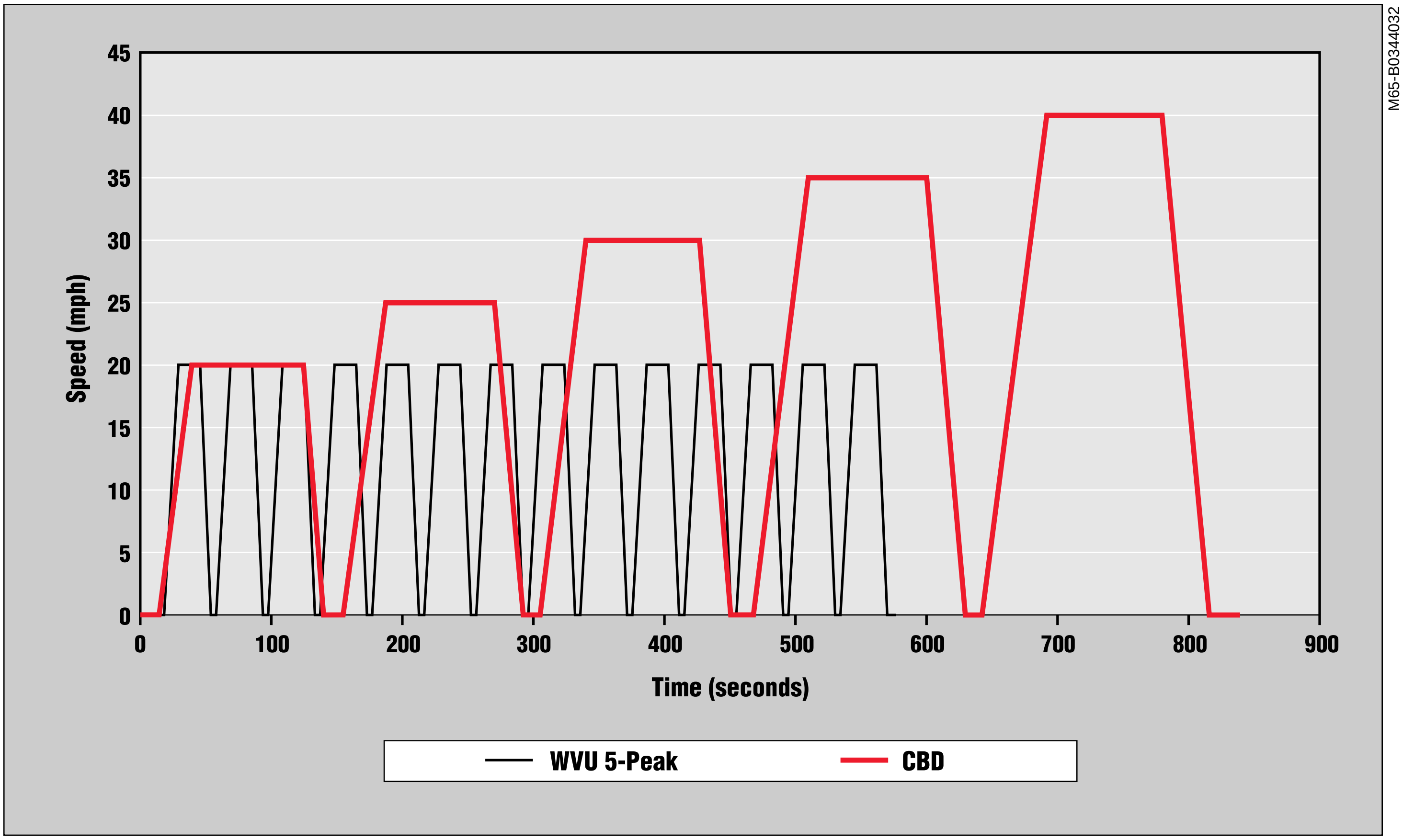


Figure 32. West Virginia University's 5-peak driving cycle compared to the Central Business District driving cycle

in over-the-road line-haul applications, whereas transit buses typically have automatic transmissions and are operated in stop-and-go urban driving conditions. These differences are important to consider when performing chassis dynamometer emissions tests and interpreting the results.

Another factor to consider when emissions testing heavy-duty vehicles is the driving cycle. Although the Central Business District chassis dynamometer driving cycle is an accepted test cycle for buses, many large trucks with manual transmissions are unable to accomplish the rapid accelerations and braking requirements of that test. Development of a more appropriate test cycle for heavy-duty trucks is the topic of several ongoing research projects. In the interim, West Virginia University has designed a "5-peak" driving cycle (see Figure 32) that can be driven by most large heavy-duty trucks. Except where noted, the results reported here for the vehicles in the Federal heavy-duty demonstration program are based on this 5-peak driving cycle.

Emissions Test Results from Ethanol Trucks

During 1994 and 1995, West Virginia University personnel made two trips each to Peoria and Minneapolis to test the emissions of heavy-duty trucks powered by Detroit Diesel Corporation 6V92 engines operating on 95 percent ethanol. In Peoria, four ethanol trucks and one diesel (control) line-haul truck owned and

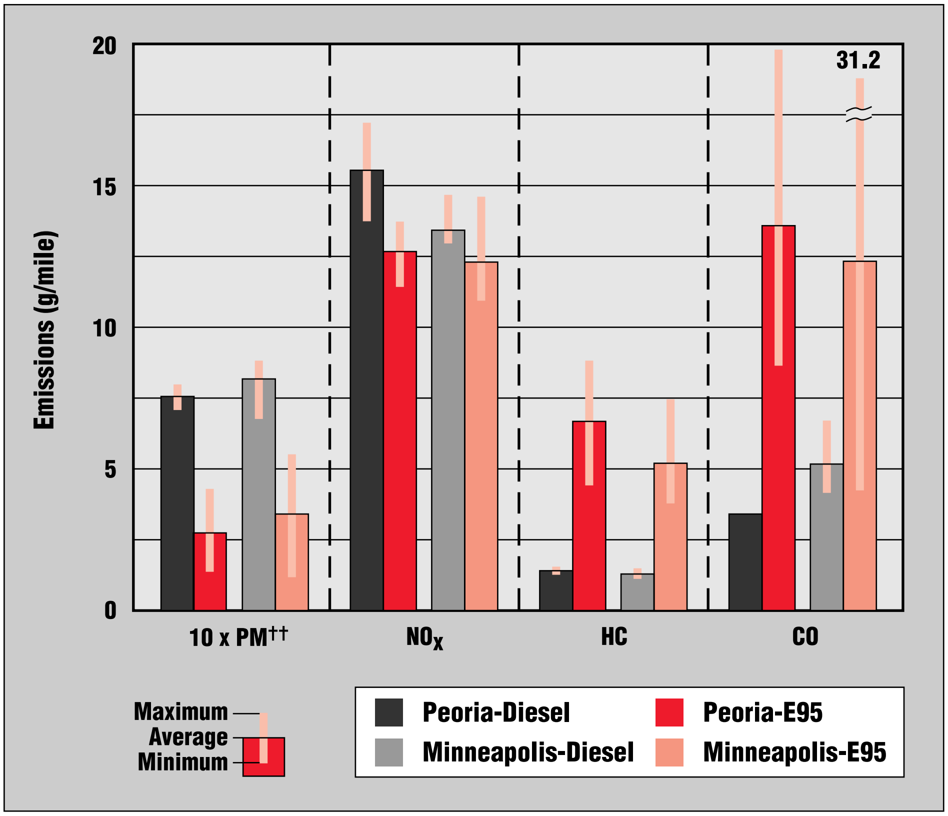


Figure 33. Comparative emissions results for ethanol and diesel trucks in Peoria and Minneapolis

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

operated by Archer Daniels Midland were tested. In Minneapolis, two ethanol snowplows and one diesel (control) snowplow belonging to Hennepin County were tested.

For various emissions constituents, Figure 33 shows the average, minimum, and maximum values observed in the trucks tested in Peoria and Minneapolis. Although the two engine applications are quite different (snowplow versus line-haul tractor), the average observed emissions are similar. At both locations, the average particulate matter detected in the ethanol trucks was less than 50 percent of the corresponding diesel value for their diesel counterparts, the average oxides of nitrogen observed in the ethanol trucks were marginally lower than in their diesel counterparts, and the average hydrocarbon and average carbon monoxide values were observed to be higher in ethanol trucks than in diesel trucks. Also, emissions results from ethanol trucks at both locations are more variable than the corresponding values from diesel trucks, especially in the case of carbon monoxide and hydrocarbons.

In general, the emissions from the heavy-duty trucks are similar to those for transit buses operating on ethanol Detroit Diesel Corporation 6V92 engines. For the large trucks and buses, average particulate matter and oxides of nitrogen are lower for the ethanol vehicles. However, hydrocarbon and carbon monoxide emission levels are higher than those of their diesel counterparts.

As with the transit buses, ethanol heavy-duty trucks show potential for contributing to cleaner air by reducing levels of particulate matter and oxides of nitrogen. However, the higher variability in individual emissions results from these ethanol vehicles may point to the need for further technological improvements. To this end, results from the Federal heavy-duty demonstration program are being communicated to the engine manufacturers to help them identify and correct the problems associated with the high emitters.

Emissions Results from Compressed Natural Gas Garbage Packers

Also during 1994 and 1995, West Virginia University personnel tested six compressed natural gas and three diesel New York City Department of Sanitation garbage packers for emissions output. These vehicles were tested using the Central Business District driving cycle because they typically operate in urban service, and because they are equipped with automatic transmissions. The engines in the compressed natural gas garbage packers represent early demonstration versions of the Cummins L10GG, which have been available since 1992. Cummins engineers have indicated that the vehicles powered by these engines were placed in fleets as "proof of concept" vehicles, and were not optimized for emissions reductions. As expected, the emissions results from these vehicles have been mixed, but are reported here for completeness. They also establish a benchmark against which new compressed natural gas technologies can be compared.

Figure 34 shows the average, minimum, and maximum emissions from the New York City garbage packers. The average particulate matter from the compressed natural gas vehicles is very low. In six of eleven tests performed to date, particulate matter levels are essentially zero (that is, too low to measure), and the diesel vehicles average approximately 0.7 grams per mile. Again, as in the case of transit buses, this is an attractive feature of compressed natural gas, because these vehicles operate in populated urban areas where particulate matter from vehicle exhaust is a serious human health concern.

On the other hand, the average hydrocarbons emissions from the compressed natural gas garbage packers are higher than the corresponding values for the diesel garbage packers. As in the case of transit buses, hydrocarbon emissions from the compressed natural gas vehicles typically comprised 90 percent to 95 percent methane. The Environmental Protection Agency and California Air Resources Board regulations are written in terms of non-methane hydrocarbons because methane is considered to be non-reactive in the atmosphere. However, methane is a potent greenhouse gas—far more active than carbon dioxide. The non-methane hydrocarbon levels from the compressed natural gas garbage packers were not measured directly, but the values are projected to be similar to or lower than those observed in the diesel garbage packers.

The carbon monoxide and oxides of nitrogen levels observed in the compressed natural gas garbage packers are not as encouraging. Individual values of carbon monoxide and

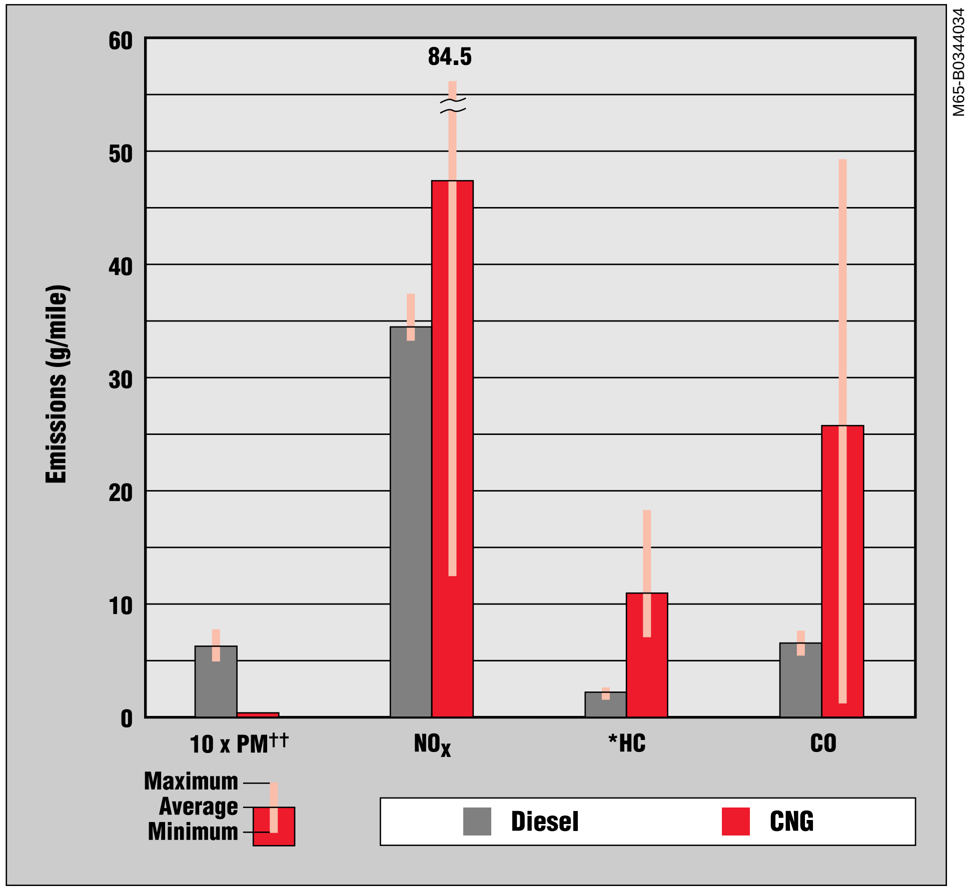


Figure 34. Emissions results for New York City garbage packers

* Total hydrocarbons.

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

oxides of nitrogen vary greatly, but most test results were notably higher than the corresponding results for garbage packers operating on diesel. It should be noted that the compressed natural gas engines on which the tests were conducted are "uncertified" with regard to emissions. As in the case of these engines deployed in transit buses, later versions have been optimized for emissions reduction, and early tests on the enhanced models show substantial reductions in the levels of carbon monoxide and oxides of nitrogen (see the section on transit bus emissions for further discussion). There are plans to pursue emissions testing of the newer model, certified engines as they are put into service in heavy-duty fleets.

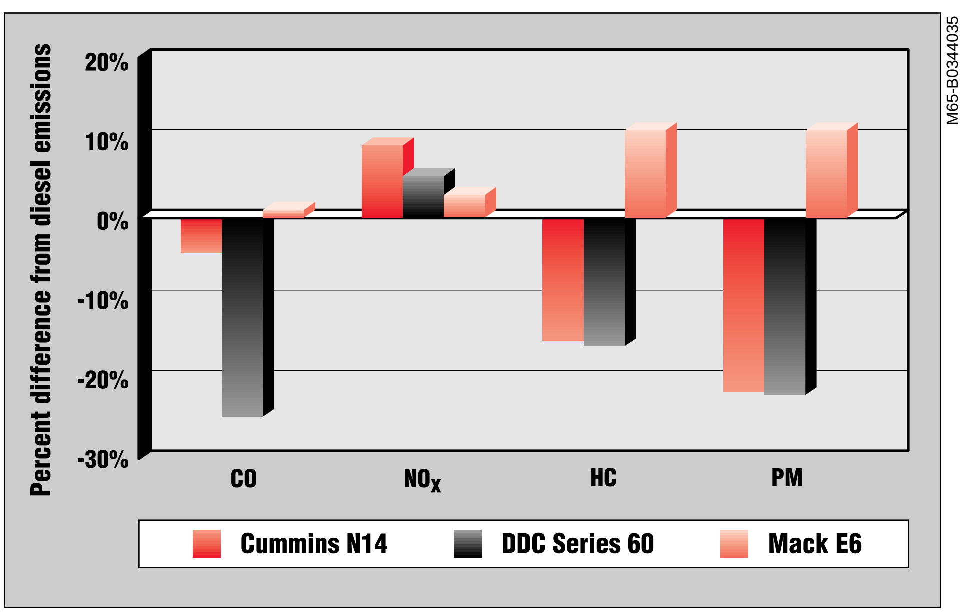
Emissions Results from AG Processing Corporation's Biodiesel Blend Line-Haul Trucks

During 1995, West Virginia University personnel performed the first round of emissions tests on trucks operating on biodiesel blend (biodiesel blends other than B100 are not considered by the U.S. Department of Energy to be alternative fuels under the provisions of the Act). There are six large heavy-duty trucks in Iowa operating on biodiesel blend, which are part of AG Processing Corporation's line-haul fleet. All six were previously operated as standard diesel trucks. The biodiesel blend is composed of 35 percent methyl ester of soya oil and 65 percent diesel.

The emissions test procedures for these trucks differ from those discussed so far, in that each vehicle was first tested on biodiesel blend and then retested on standard diesel fuel. This approach allows for a direct comparison of the emissions from the two fuels on each truck.

Of the six biodiesel trucks, two are powered by Cummins N14 engines, two by Detroit Diesel Corporation Series 60 engines, and two by the Mack E6 engine. Each vehicle was emissions tested on biodiesel blend, operated for approximately one week on conventional diesel, and then retested on diesel. The results from the emissions tests are summarized in Figure 35. The vehicles with the Cummins N14 and Detroit Diesel Series 60 engines all exhibited a decrease in average carbon monoxide, particulate matter, and hydrocarbon emissions when tested on biodiesel blend, relative to the average values for these same vehicles tested on diesel. The particulate matter and hydrocarbon averages ranged between 15 percent and 23 percent below the corresponding values

Figure 35. Emissions results for biodiesel blend line-haul trucks (biodiesel blends other than B100 are not presently considered to be alternative fuels by the U.S. Department of Energy)



for diesel. In addition, all engine makes registered a small (less than 10 percent) increase, on average, in oxides of nitrogen when tested on biodiesel blend relative to the corresponding averages obtained on diesel. The trucks with Mack E6 engines are all high-mileage vehicles. Although the average values for all emissions for these vehicles were higher when tested on biodiesel blend than those obtained when tested on diesel, the results for individual trucks were mixed.

These results are preliminary in that they are the first heavy-duty truck chassis dynamometer tests run on two fuels back to back. Results from the most consistent of the engines agree well with results from dynamometer tests conducted on both fuels individually in the laboratory. Additional on-site emissions tests will be conducted on the biodiesel blend trucks on site in Iowa during 1996. The additional data collected should allow more rigorous conclusions to be drawn.

Federal Express CleanFleet

In addition to the emissions test results available from the heavy-duty vehicles included in the heavy-duty demonstration program, additional emissions information has been obtained from the medium-duty vans included in the Federal Express CleanFleet project. This project was partially funded by the U.S. Department of Energy.

In the CleanFleet project, 36 delivery vans were emissions tested at each of three different mileage levels. The first round of tests was performed at about 4,000 miles, the second at about 14,000 miles, and the third at the end of the project (25,000 to 35,000 miles). Three vans from each combination of vehicle manufacturer and fuel type were tested.

The California Air Resources Board conducted the emissions tests using a chassis dynamometer running the Federal Test Procedure. Industry-average standard unleaded test gasoline (RF-A) was used in the control vehicles for purposes of comparison.

The CleanFleet compressed natural gas vehicles emitted an average of 65 percent to 80 percent less carbon monoxide than otherwise identical 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; the vehicles using catalytic converters designed for natural gas exhaust had lower average oxides of nitrogen emissions, and the Ford vans using catalytic converters designed for gasoline exhaust had higher average oxides of nitrogen emissions. However, there is considerable variability among the results for individual vehicles. Except for the oxides of nitrogen emissions from the Ford vans, the difference in emissions between the compressed natural gas and gasoline vehicles did not change dramatically from one mileage level to the next.

In contrast, the difference in emissions from delivery vans operating on propane and their counterparts operating on gasoline did become more pronounced with increasing mileage. Generally, the average

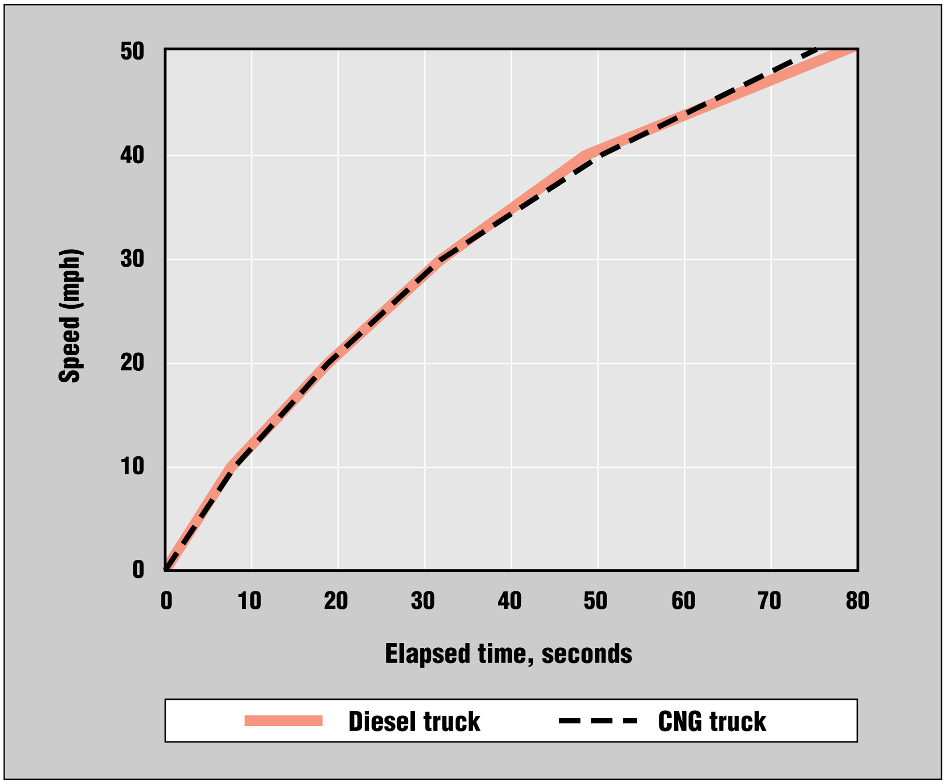
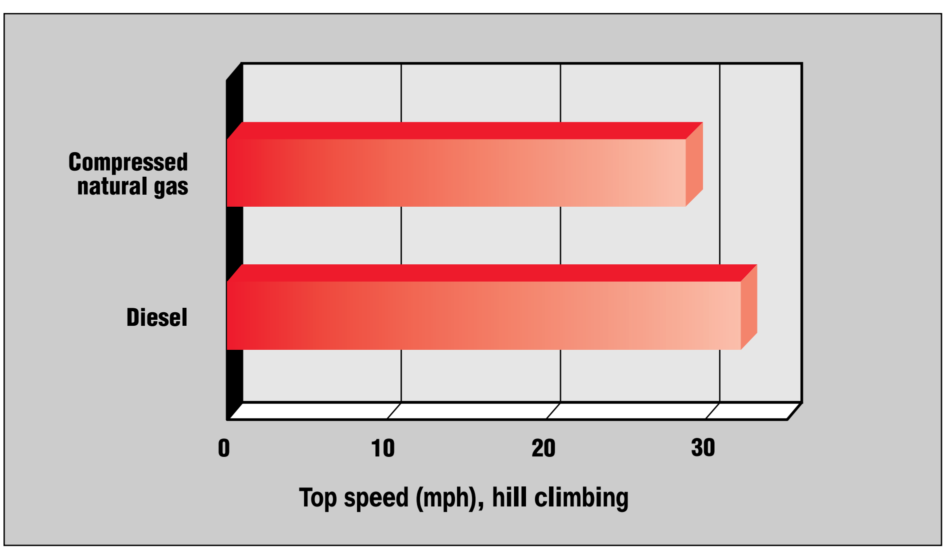


Figure 36. Acceleration performance of the Vons compressed natural gas and diesel trucks

Figure 37. Hill-climb performance of the Vons compressed natural gas and diesel trucks



emissions levels from the propane vans remained relatively constant, but the gasoline control vans exhibited increasing values with increasing mileage.

In particular, the propane vehicles emitted less carbon monoxide on average, but slightly more hydrocarbons, on average, than their gasoline-powered counterparts. A substantial portion of the emitted hydrocarbons was unburned propane, which is relatively non-reactive, photochemically, in the atmosphere. The results for oxides of nitrogen were mixed, with individual tests and individual vans being highly variable.

The overall results from the Ford vans running on 85 percent methanol were also highly variable. One conclusion is that these vehicles tended to exhibit lower average carbon monoxide emissions than their gasoline counterparts at various mileage levels.

Performance and Reliability

Vehicle performance for heavy-duty trucks and commercial delivery vans encompasses such factors as acceleration, hill climbing, driveability, and driver acceptance. Information about the performance of these kinds of vehicles is collected in two ways: direct measurements are taken on parameters such as acceleration and hill climbing, and driver feedback is solicited and recorded.

To directly assess the performance of heavy-duty trucks operating on alternative fuels, acceleration and hill climbing capability of a compressed natural gas line-haul truck operated by Vons Grocery Company and a diesel counterpart were measured in controlled tests. Acceleration was tested using six consecutive runs in opposite directions on a single one-mile length of road. The hill-climb tests were conducted on Kellogg Hill, one of the larger hills in the greater Los Angeles freeway system. Both trucks were hauling a trailer containing a typical load.

The results of these tests are shown in Figures 36 and 37. Acceleration for the two trucks was nearly identical. In the hill-climbing test, the compressed natural gas truck's top speed was about two miles per hour slower than that of its diesel counterpart.

The sidebar on page 62 highlights specific performance and reliability issues that have surfaced with the vehicles in the Federal heavy-duty demonstration program. These issues vary from one location to the next. As a direct result of this field experience, the manufacturers of the engines included in this program have already made significant design improvements. Additional evidence and experience can only lead to further performance improvements in heavy-duty alternative fuel engines.

Fuel Economy

Delivery Vans

All fuel economy data for the CleanFleet delivery vans have been collected and analyzed. Figure 38 presents a summary of the final in-use and chassis dynamometer fuel economy information on a mile per gasoline-equivalent-gallon basis. In general, all the chassis dynamometer results are higher than the corresponding in-use values. This result is probably due to a difference in the driving cycle of urban delivery vans in comparison to the driving cycle used in the dynamometer test. For example, a typical van usage pattern includes more stopping and idling than outlined in the Federal Test Procedure driving cycle.

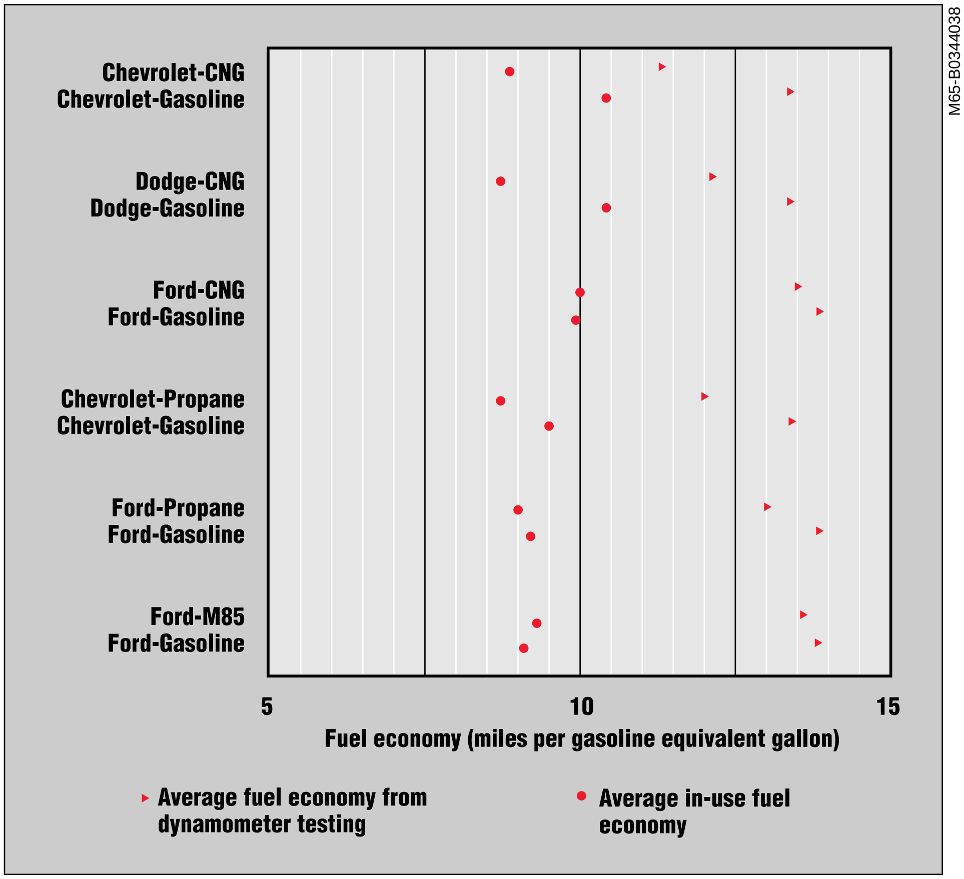


Figure 38. CleanFleet fuel economy results for delivery vans

In accordance with these considerations, the Chevrolet propane and compressed natural gas vans and Dodge compressed natural gas vans achieved 10 percent to 15 percent lower in-use fuel economy than their gasoline counterparts. The corresponding dynamometer results for these same vehicles mirror this result. The fuel economy achieved by all the Ford vehicles (compressed natural gas, propane, and 85 percent methanol) was within a few percentage points of the fuel economy achieved by their gasoline counterparts. This was true for both the in-use and dynamometer types of measurements.

Large Trucks

Each time a truck is refueled, the driver records the quantity of fuel put into the truck and its odometer

Heavy-Duty Vehicle Performance and Reliability Issues

Project	Fuel	Performance	Reliability
Federal Express CleanFleet	85 percent methanol, compressed natural gas, liquefied petroleum gas, gasoline, electricity	Driveability and range complaints	Original equipment manufacturer engines generally better than conversions
Vons Grocery Company Truck	Compressed natural gas	Hill-climb test slower than diesel; acceleration comparable to diesel	Numerous reliability problems indicate lack of development
New York City Garbage Packer	Compressed natural gas	Comparable performance; much quieter	One low-mileage piston failure
Illinois Dept. of Commerce and Community Affairs/ Arthur Daniels Midland truck	95 percent ethanol	Comparable performance	Bearing failure caused by operator error*
Hennepin County and Nebraska Highway Department Snowplow	95 percent ethanol	Performance complaints related to fuel pumps; cold-starting problems; stalling problems	Fuel pump failures
Los Angeles Times Truck	Compressed natural gas	Comparable performance in general, some hard starting	High oil consumption (upgrades are being installed to solve the problem), fuel line rupture (fuel line routing was redesigned)
AG Processing line-haul truck	35 percent biodiesel blend**	Drivers may have reported hesitation and lack of power	No reliability problems to date

* A new operator thought that the Detroit Diesel Company-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.

** Biodiesel blends other than B100 are not considered by the Department of Energy to be alternative fuels under the Act.

reading. From these records, the in-use fuel economy of the vehicle can be calculated. When the vehicle is tested for emissions on the transportable chassis dynamometer, the fuel economy is also measured.

As in other instances, in-use fuel economy for large trucks varies from refueling to refueling because of factors such as variations in driving styles and day-to-day duties. Measurements obtained on a chassis dynamometer, on the other hand, are taken under tightly controlled conditions, and therefore exhibit less variation. As was the case in previous discussions, the disadvantage of the dynamometer tests is that the incorporated driving cycle may not be representative of the vehicle's normal operation.

With the exception of the New York City garbage packers, all large trucks in the Federal demonstration program have manual transmissions and cannot accommodate the Central Business District dynamometer driving cycle. Consequently, they were all tested using West Virginia University's 5-peak cycle. The garbage packers, on the other hand, were tested using the Central Business District driving cycle.

Figure 39 summarizes the fuel economy data available to date for the vehicles in the Federal heavy-duty vehicle demonstration program. All information is presented on a mile per diesel-equivalent-gallon basis. So far, most of the alternative fuel vehicles have exhibited both in-use and dynamometer fuel economy somewhat less than their diesel counterparts.

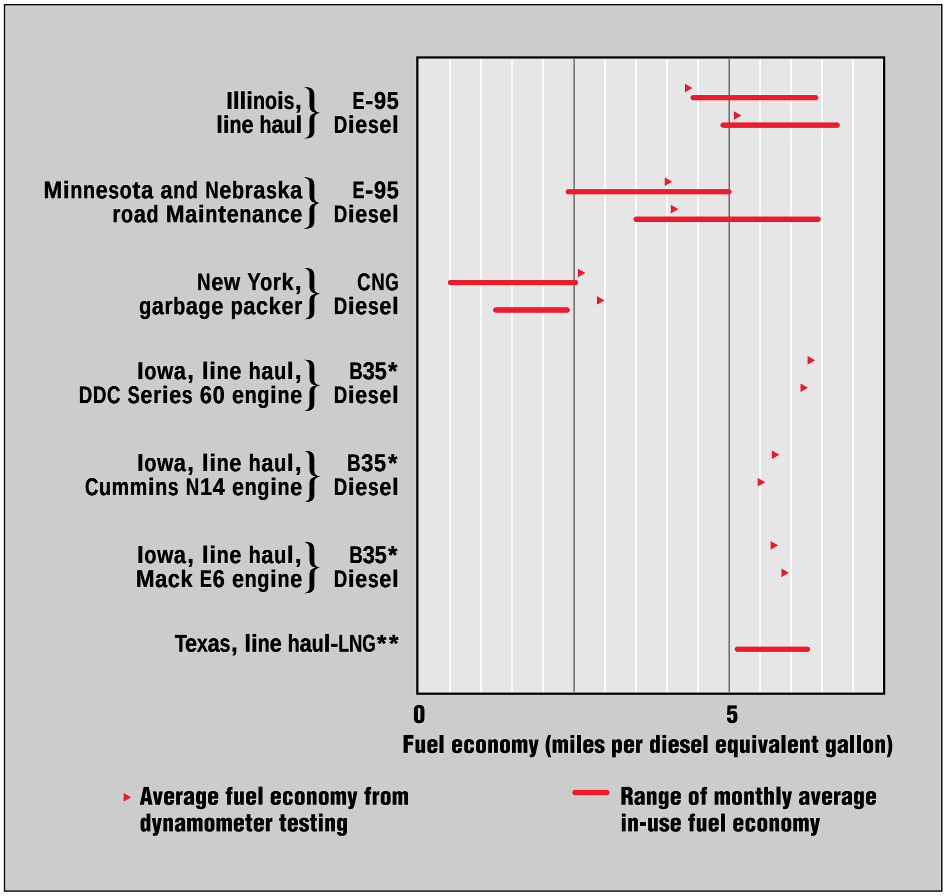


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Figure 39. Fuel economy data available to date in the Federal heavy-duty vehicle demonstration program

* B35 is not considered an alternative fuel by the U.S. Department of Energy at this time.

** Based on a small sample of preliminary data (diesel data not yet available).

A number of trucks operating on 35 percent biodiesel blend (not presently considered by the U.S. Department of Energy to be an alternative fuel) in Sheldon, Iowa, were recently added to the program. Although West Virginia University personnel have visited the site and taken fuel economy measurements using the portable chassis dynamometer, there are insufficient in-use refueling data to report at this time. Also, a number of large trucks operating on liquefied natural gas in Texas have recently been added to the heavy-duty demonstration program, but West Virginia University personnel have not yet conducted tests on these trucks.

Cost

Keeping operating costs low is critical to successful heavy-duty vehicle operations, as it is for service functions performed by such vehicles as delivery vans. For example, the American Trucking Association reports that in line-haul trucking, the profit margin is very narrow—on the order of 2 percent. This means that any increase in operating cost either makes the operation unprofitable or increases the price the consumer must pay.

Incremental Acquisition Costs

Acquiring a new alternative fuel heavy-duty truck has generally required several steps:

- Identifying and acquiring an appropriate alternative fuel engine
- Acquiring the fuel system
- Acquiring the chassis
- Hiring an engineering firm to design and execute the build-up of the vehicle.

As expected, equipping a heavy-duty truck to use alternative fuels is more expensive than equipping a similar truck to operate on diesel. In the case of compressed natural gas, heavy-duty engines carry an incremental cost of $15,000 to $20,000. The incremental cost of the fuel system exceeds the incremental cost of the engine, and it differs depending on type of chassis and the fuel of interest. The liquefied natural gas fuel system for trucks recently added to the Federal demonstration program cost about $12,000. Other incremental costs are associated with designing and executing vehicle build-up. The design phase costs about $30,000 per vehicle, and actual build-up costs are about $15,000 per vehicle.

These expenses are a major disincentive to fleet operators interested in using alternative fuel trucks. However, as the heavy-duty alternative fuel market develops, such costs are expected to decrease. Beginning in 1996, several chassis manufacturers will begin offering alternative fuel trucks as a package, eliminating the need to go through the steps outlined above. In principle, an alternative fuel engine should not be inherently a great deal more expensive to manufacture than a diesel engine. Therefore, as the market expands, and research and development costs are recouped, the engine cost should approach the cost of diesel engines. The same can be said for chassis costs.

The fuel system for compressed and liquefied natural gas, in contrast, is inherently more complex than a diesel fuel system and will probably continue to be more expensive. However, the fuel system cost is a relatively small part of the total cost of the vehicle. A small incremental cost for the fuel system could easily be recovered in lower fuel costs.

Comparative Fuel Costs

Truck fleets tend to consume large amounts of fuel, making fuel cost a large part of the total operating cost of a trucking company—second only to personnel costs. For this reason, a change of a few cents per gallon can make a substantial impact on the ability of alternative fuels to compete in the trucking business.

As noted previously, the cost of alternative fuels varies from one fuel to another, both regionally and over time. Federal and state taxes also figure heavily in fuel cost.

The Department of Energy's publication entitled *Guide to Alternative Fuel Vehicle Incentives and Laws* itemizes many of the varying state incentives and taxes applicable to purchasers of alternative fuels. Figure 40 shows representative fuel cost per diesel equivalent gallon for the fuels being used in the Federal heavy-duty vehicle demonstration program. Federal and state taxes are included in the figures.

The costs presented for ethanol, compressed natural gas, and diesel are based on published national average station prices. However, comparative prices are not available for liquefied natural gas because of the lack of infrastructure for this fuel. The same is true for biodiesel blends, which, other than neat biodiesel (B100), are not considered by the Department of Energy to be alternative fuels under the provisions of the Act. Instead, a cost is presented for B35 (a low-level biodiesel blend) based on the price paid at the Federal biodiesel demonstration site in Sheldon, Iowa. The cost shown for liquefied natural gas is based on the cost at a liquefaction plant for liquefied natural gas with 95 percent to 97 percent methane content. Currently, there are 15 liquefaction plants throughout the country. For a trucking company that is not located near a liquefaction plant, transportation cost adds about $0.07 per diesel equivalent gallon for every 100 miles from the plant.

It is clear from Figure 40 that compressed and liquefied natural gas can potentially save a trucking company money, but that saving is not automatic. The total saving per vehicle depends on the number of miles the vehicle travels per day and the cost differential between the alternative fuel and diesel. This cost saving must be balanced against the incremental cost of the alternative fuel vehicle and any infrastructure changes required. Trucking companies expect a payback period of two to three years to justify investing in alternative fuels. There are indications that natural gas may be economically justified in some high-mileage applications right now. As the incremental cost of natural gas vehicles decreases, a greater variety of trucks will be able to reap economic benefits from using natural gas. Economic advantage is the only force great enough to drive the widespread use of alternative fuels in trucking.

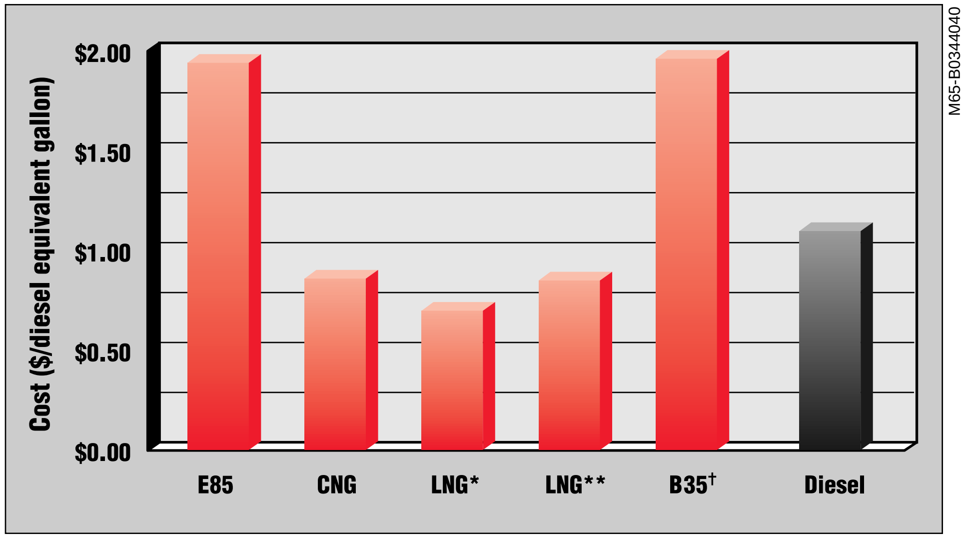


Figure 40. Average retail fuel costs per diesel equivalent gallon (with tax)

* Taxed as CNG.

** Taxed as "special motor fuel."

† Price in Sheldon, IA, only. B35, a low-level biodiesel blend, is not considered an alternative fuel by the U.S. Department of Energy at this time.

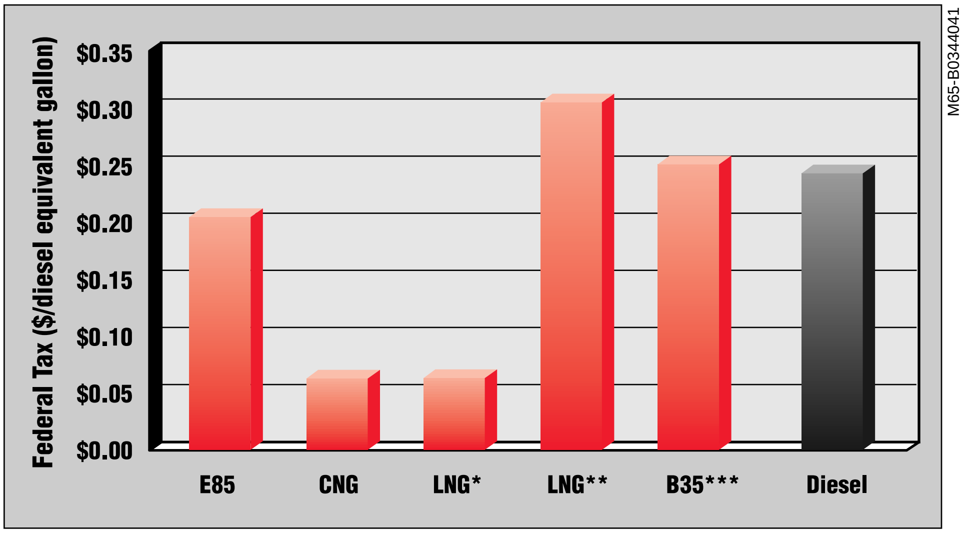


Figure 41. Federal fuel tax per diesel equivalent gallon

* Taxed as CNG.

** Taxed as "special motor fuel."

*** A low-level biodiesel blend not currently considered by the Department of Energy to be an alternative fuel under the provisions of the Act.

As mentioned previously, a difference of a few cents per gallon can change the economics from a benefit to a detriment for a specific trucking application. This means that the fuel tax structure will play a major role in determining whether alternative fuels are widely used. The Federal fuel tax on the alternative fuels used in the Federal heavy-duty vehicle demonstration program is shown in Figure 41. The tax is shown on an equal energy basis for direct comparison. Two bars are included for liquefied natural gas because there have been two interpretations regarding the taxes applied to this fuel. Until recently, liquefied natural gas could be taxed either as compressed natural gas or as a "special motor fuel" (the category that liquefied petroleum gas falls into). However, on August 7, 1995, the U.S. Internal Revenue Service published a ruling in the Federal Register requiring liquefied natural gas to be taxed at the higher special motor fuel rate. This deals a serious blow to the use of liquefied natural gas in trucking. Several parties, including the National Gas Vehicle Coalition and the American Trucking Association, are challenging the ruling.

Comparative Maintenance Costs

Virtually all the heavy-duty alternative fuel vehicles in the Federal demonstration program cost more to maintain than their diesel counterparts. Most vehicles in the program represent prototype, field-test technology, and part of the reason for deploying and tracking them is to work out the bugs in the technology so it can be moved closer to commercialization. Higher maintenance costs are to be expected for such vehicles. As alternative fuel engine manufacturers accumulate experience through such programs, the reliability of the engines will increase and maintenance costs should approach those of their diesel counterparts. Beginning in 1996, a vehicle evaluation program modeled after the transit bus program will be initiated to evaluate the maintenance costs of the newly available production heavy-duty alternative fuel vehicles side by side with comparable diesel vehicles.

Summary

The heavy-duty alternative fuel industry is still in its early stages of development. The Federal heavy-duty alternative fuel demonstration program has been a catalyst in that development process. The feasibility of new technologies has been demonstrated with the Archer Daniels Methanol trucks running on ethanol. Technology has been refined

Photo courtesy of CH•IV Cryogenics/PIX 03316

LNG fueling dispenser

Liquefied Natural Gas Refueling Becomes "Self Serve"

Liquefied natural gas is cryogenically stored at 260 degrees Fahrenheit below zero. Because it is a denser fuel than compressed natural gas and is stored at a lower pressure, liquefied natural gas fuel tanks are smaller and lighter than compressed natural cylinders. This gives liquefied natural gas an advantage for trucks that require a long operating range between refuelings.

In the past, however, refueling with liquefied natural gas looked like a scene out of a NASA documentary. Trained technicians required special suits and face masks to protect themselves from the cryogenic liquid. The picture is now changing with the introduction of new "self-serve" liquefied natural gas refueling technology.

To date, three retail liquefied natural gas stations have been installed—one each in Los Angeles, Denver, and Bloomfield, New Mexico. All three of these stations are card operated and sell directly to the consumer. In Los Angeles, where one of the new test vehicles in the Federal heavy-duty demonstration program will refuel, a discount is offered to any customer who completes a short training course on the use of the station. A station attendant refuels the vehicle when its driver has not received the training.

Jeffery Beale, president of CH•IV Cryogenics, describes the new technology in this way: "Imagine fueling your personal gasoline vehicle . . . that's how simple and safe our new installation has made fueling an LNG vehicle." The CH•IV design uses a single hose (analogous to a gasoline hose), and purges the fuel from the nozzle before connecting or disconnecting, so the driver is not exposed to the fuel.

through on-road field testing using the Vons compressed natural gas truck. Acceptance of alternative fuel vehicles has been increased through use of the United Parcel Service compressed natural gas delivery vans. Finally, technology has been moved closer to commercialization through the use of the *Los Angeles Times* compressed natural gas truck.

In 1996, heavy-duty trucks equipped to run on alternative fuels will be available directly from the truck manufacturers for the first time. The industry has made its choice among the many alternative fuels: the new vehicles will be available for natural gas only (both compressed and liquefied). Propane vehicles may become available in 1997.

In 1996, the Federal demonstration program will begin side-by-side evaluations of the new production alternative fuel trucks with comparable diesel-powered trucks. This evaluation effort will be patterned after the Federal transit bus evaluation project.

Aftermarket Vehicle Conversions

Overview

The Energy Policy Act of 1992 (42 U.S.C. 13212 (a) and (b)) specifies minimum purchase requirements for alternative fuel vehicles in the Federal fleet. The schedule for acquiring light-duty alternative fuel vehicles follows:

- FY 1993 — 5,000 vehicles
- FY 1994 — 7,500 vehicles
- FY 1995 — 10,000 vehicles
- FY 1996 — 25 percent of Federal fleet acquisitions
- FY 1997 — 33 percent of Federal fleet acquisitions
- FY 1998 — 50 percent of Federal fleet acquisitions
- FY 1999 and after — 75 percent of Federal fleet acquisitions

The Federal government normally acquires about 50,000 vehicles each year.

Although alternative fuel vehicles have been under development for more than a decade, their availability from the automobile manufacturers was not sufficient in calendar year 1992 to allow the various Federal agencies to meet the requirements of the Act. The decision was made to use aftermarket conversions to fill the gap until a sufficient number of original equipment models could be made available at a reasonable cost. Aftermarket conversions involve equipment additions after the vehicle is sold, to allow vehicles originally designed for one fuel to operate on another. There are many U.S. companies that convert light-duty gasoline vehicles to allow them to operate on compressed natural gas or liquefied petroleum gas.

In February 1992, the National Renewable Energy Laboratory initiated a competitive procurement for aftermarket conversion of vehicles in the Federal fleet. Such conversions enable the vehicles to operate on an alternative fuel. The procurement was initiated to develop subcontracts with several alternative fuel vehicle conversion companies across the nation, with the goal of converting about 1,000 Federal government vehicles. The U.S. Department of Energy provided the funding for these conversions. As of August 1995, about half of the targeted conversions were completed, with the remainder either on order or in the planning stages.

The conversion effort has succeeded in helping the Federal government meet the requirements of the Act during a period of limited model availability. Activities will be phased down during 1996, however, because original equipment availability has significantly improved.

Table 4. Expansion of Alternative Fuel Vehicle Availability between 1992 and 1996

1992 Model Year Vehicles

Manufacturer	Model	Body Style	Fuel
Chrysler-Dodge	Ram van/wagon	Full-size van	CNG
GM-Chevrolet	C1500/C2500	Full-size pickup	CNG
GM-Chevrolet	Lumina	Mid-size sedan	Ethanol
Ford	F700	Medium-duty truck	LPG

1996 Model Year Vehicles

Manufacturer	Model	Body Style	Fuel
Chrysler-Dodge	Ram van/wagon	Full-size van	CNG
Chrysler-Dodge	Ram pickup	Full-size pickup	CNG
Chrysler-Dodge/ Plymouth	Caravan/Voyager	Minivan	CNG
Ford	Contour	Compact sedan	CNG/Bi-fuel
Ford	Taurus	Mid-size sedan	Methanol
Ford	Taurus	Mid-size sedan	Ethanol
Ford	Crown Victoria	Full-size sedan	CNG
Ford	F150/F250	Full-size pickup	CNG
Ford	Econoline	Full-size van	CNG
Ford	F150/F250	Full-size pickup	LPG/Bi-fuel
Ford	F700	Medium-duty truck	LPG

Table 4 compares the availability of alternative fuel vehicles from the original equipment manufacturers at the start of the Federal light-duty program in 1992, with their corresponding availability in 1996, and illustrates the expanded product availability during this time frame.

Program Description

At this time, light-duty vehicles are commonly converted to operate on one of two alternative fuels: compressed natural gas or liquefied petroleum gas (propane). Aftermarket conversions inherently represent a compromise of vehicle technology, so a key program objective is to obtain the highest-quality conversions available. Consequently, when selecting subcontractors to perform the work, experience, capabilities, and demonstrated ability to meet the high performance criteria were weighted more heavily than price. With regard to actual equipment, only higher-quality, “closed-loop, feedback” conversion kits were used, because these are known to provide the best emissions performance. Best industry practices were required during installation of the kits. For instance, all compressed natural gas conversions were installed according to the National Fire Protection Association’s Specification 52. This specification includes detailed instructions for installing the fuel system and tank. Similarly, liquefied petroleum gas conversions were installed according to the National Fire Protection Association’s Specification 58.

Vehicles converted to operate on compressed natural gas have a minimum specified driving range of 70 miles. In most cases, however, the range is substantially more. In contrast, vehicles converted to operate on liquefied petroleum gas have a minimum specified driving range of 170 miles.

Each aftermarket vehicle conversion is protected by a warranty that covers all installed conversion system parts and associated labor for three years or 36,000 miles, whichever comes first. Conversion subcontractors are also responsible to repair or replace any engine, fuel system, electrical, or electronic system components damaged by the installed conversion equipment during this period. As required by the provisions of the Act, subcontractors are required to sign individual warranty agreements with Chrysler, Ford, and General Motors.

The first light-duty vehicle conversions were completed during the summer of 1994. Conversion activities are continuing through the date of this writing.

Table 5 shows the total number of conversions currently completed, planned, or on order, by Federal agencies as of August, 1995.

Figure 42 shows the distribution of conversions, by state, that are completed, planned, or on order.

Figure 43 shows the distribution of conversions, by vehicle type, that are completed, planned, or on order.

Figure 43 illustrates that more than 90 percent of all conversions are taking place on pickups and vans. This is a good sign because the original equipment manufacturers are concentrating on producing these same types of vehicles.

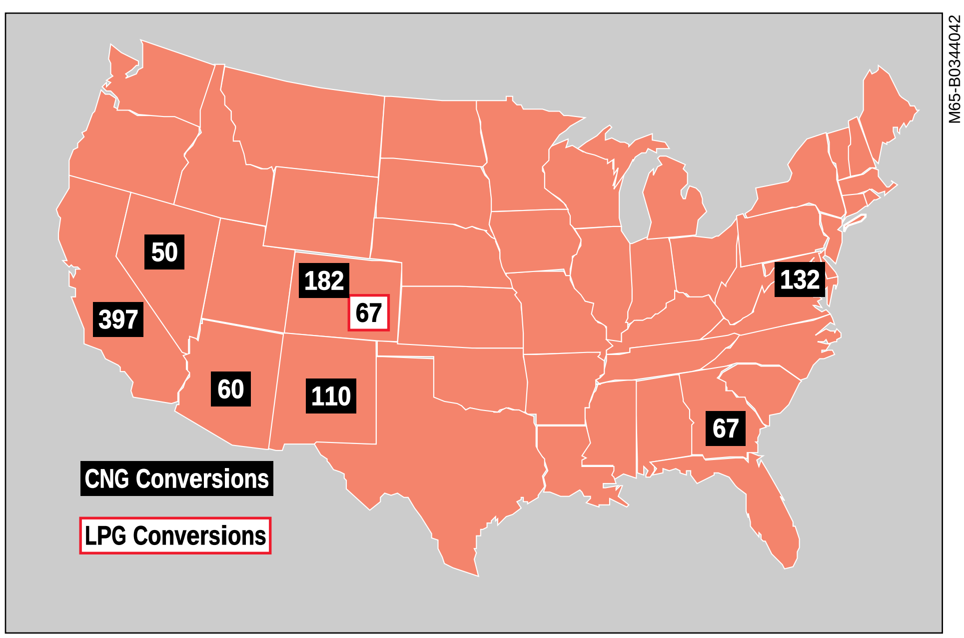
Most light-duty vehicle conversions (more than 92 percent) are bi-fuel conversions, which means that the vehicle may operate on either gasoline or the designated alternative fuel. The remainder are "dedicated" conversions, which means that the vehicles may operate only on the designated alternative fuel.

The cost of a light-duty vehicle conversion depends on the alternative fuel of interest, the level of conversion technology used, and the size

Table 5. Conversions by Federal Agency

Agency	CNG	LPG	Total Vehicles
Air Force	414	0	414
Marines	220	0	220
General Services Administration	160	40	200
Navy	97	0	97
National Institutes of Health	67	0	67
Forest Service	32	24	56
Other Federal Agencies	8	3	11
Totals	998	67	1065

Figure 42. States in which aftermarket conversions included in the program are located



or quantity of the fuel tanks. The average total cost for each compressed natural gas conversion in the program is about $4,500. The average total cost for each liquefied petroleum gas conversion, on the other hand, is about $2,700. The overall cost of each conversion, especially in the case of compressed natural gas, depends heavily on the number and size of the fuel tanks. The fuel tanks specified for each conversion, in turn, depend on the vehicle type and desired range. For some vehicles, more than one tank is installed.

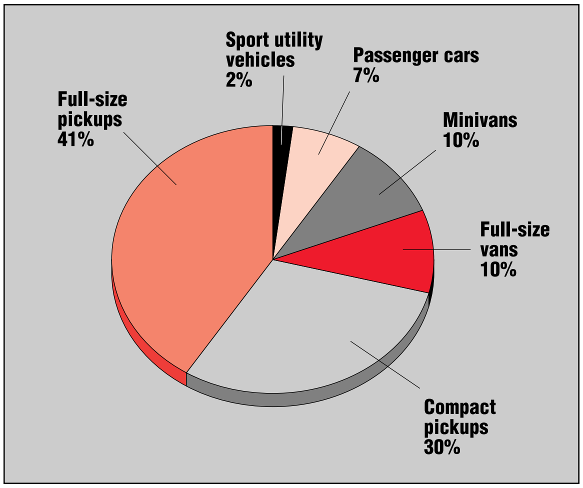


Figure 43. Vehicle conversions by vehicle type (1,065 total)

Where possible, every effort was made to target vehicles located in cities designated by the U.S. Department of Energy as "Clean Cities." Converted vehicles will be operating in six of the 45 communities designated as Clean Cities (as of April 1, 1996): Atlanta; Denver; Las Vegas; Washington, D.C.; Albuquerque; and Colorado Springs.

Emissions Results

During the 1995 fiscal year, the program began testing emissions on a limited number of these aftermarket conversion vehicles. A very large test matrix of vehicles and conversion kits would need to be tested to fully answer the question of how various conversion kits perform on a large cross-section of vehicle types, given the expected variability in individual vehicle performance and emission test results. As an initial step, emissions testing was begun in 1995 on a limited number of vehicles included in the Federal aftermarket conversion program. Sixteen vehicles, including eight new vehicle models, and two different conversion kits (one each for compressed natural gas and liquefied petroleum gas) were included in this effort. A list of the number and type of vehicles is shown in Table 6.

As stated earlier, the conversion program was designed to use only high-quality conversion systems. GFI Control Systems kits were installed in the vehicles converted to operate on compressed natural gas. Impco ADP Systems were installed in the vehicles converted to operate on liquefied petroleum gas. These modern conversion kits use electronic controls to continually adjust the air/fuel ratio based on a signal from the exhaust gas oxygen sensor. These closed-loop, feedback control conversion kits represent the state of the art of equipment available in 1995, and they constitute a minimum technological requirement for the conversion program because they are generally expected to be cleaner and more reliable than the older nonfeedback kits.

In addition to having closed-loop feedback control, the GFI kits can be electronically calibrated to a specific engine model for improved emissions performance. Consequently, an attempt has been made to test emissions on only those compressed natural gas vehicles in the conversions program for which an engine calibration exists. Furthermore, all vehicles included in the Federal conversion program were required to conform to the U.S. Environmental Protection Agency's emissions requirements for conversions (see sidebar on page 75). Other criteria used to select vehicles for emissions testing include low mileage before conversion, and similarity to original equipment alternative fuel vehicle models available from the manufacturers.

To establish an emissions baseline, each vehicle was tested on California Phase 2 reformulated gasoline before conversion. The conversion kit was installed shortly after (within 1,000 miles of) the baseline test, and subsequent emissions tests were performed first on reformulated gasoline and then on the alternative fuel (compressed natural gas or liquefied petroleum gas). The compressed natural gas used for emissions testing was specially blended from tightly controlled constituent gases, and the liquefied petroleum gas was produced to conform with the industry-accepted specification (known as HD5) for transportation propane fuel. All emissions tests conformed to the Environmental Protection Agency's Federal Test Procedures (see sidebar on test procedures on page 21) using the Urban Dynamometer Driving Schedule. In addition, standard one-hour diurnal heat-build and hot-soak evaporative test procedures were included. Plans are to test the vehicles once each year to establish emissions durability over time and accumulated mileage.

Although the first-round emissions results from the vehicles in the Federal aftermarket conversion program are somewhat mixed, the following general observations can be made. The results are summarized in Table 7.

Table 6. Converted Vehicles Emissions Tested in 1995

Compressed Natural Gas (kit make and model: GFI)

Manufacturer	Model	Quantity
Plymouth	Acclaim	2
Ford	Taurus	2
Chevrolet	Astro (minivan)	1
Dodge	(minivan)	2
General Motors	Safari (minivan)	2
Dodge	B250 full-size passenger van	2
General Motors	C1500 pickup	2
Total CNG		13

Liquefied Petroleum Gas (kit make and model: Impco ADP)

Manufacturer	Model	Quantity
Ford	F150 pickup	2
Ford	Taurus	1
Total LPG		3

In general, installing compressed natural gas conversion kits did not adversely affect the reformulated gasoline emissions profile. In other words, for most vehicles and most constituents, the difference was negligible between the emissions recorded for reformulated gasoline before and after conversion (less than 10 percent). For the liquefied petroleum gasoline conversions tested, two of three showed relatively large increases in emissions when tested

Table 4. Emission Test Results from Aftermarket Conversions

Washington DC Conversion Vehicles

Vehicle Model	Model Year	Before Conversion (RFG)			After Conversion (RFG)			After Conversion (CNG)		
		NO_x	CO	NMHC	NO_x	CO	NMHC	NO_x	CO	NMHC
Acclaim	1992	0.23	4.13	0.15	NC	◒	◒	●	○	○
Acclaim	1992	0.46	3.52	0.11	NC	◓	NC	●	◒	◒
Astro	1992	1.01	2.42	0.48	◒	NC	NC	◒	●	◒
Caravan	1992	0.75	1.30	0.23	◒	●	◓	●	●	◒
Caravan	1992	0.53	1.96	0.24	◒	◒	NC	●	●	◒
Safari	1993	1.14	4.92	0.46	NC	◒	NC	◒	NC	○
Safari	1993	1.20	6.19	0.54	NC	◒	◒	◒	◒	○
Taurus	1994	0.22	1.08	0.09	◓	NC	◒	●	●	NC
Taurus	1994	0.17	0.98	0.08	NC	◓	◓	●	●	NC

Denver CNG Conversion Vehicles

Vehicle Model	Model Year	Before Conversion (RFG)			After Conversion (RFG)			After Conversion (CNG)		
		NO_x	CO	NMHC	NO_x	CO	NMHC	NO_x	CO	NMHC
B250	1994	2.31	8.66	0.84	NC	NC	NC	◒	◓	○
B250	1994	0.65	2.75	0.16	◒	NC	NC	◒	●	○
C1500	1994	0.49	2.88	0.17	NC	◒	NC	◒	●	○
C1500	1994	0.61	3.98	0.18	NC	NC	NC	◒	●	○

Denver LPG Conversion Vehicles

Vehicle Model	Model Year	Before Conversion (RFG)			After Conversion (RFG)			After Conversion (LPG)		
		NO_x	CO	NMHC	NO_x	CO	NMHC	NO_x	CO	NMHC
F150 Pkup	1994	1.20	0.66	0.09	◒	●	●	NC	○	●
F150 Pkup	1994	0.88	0.80	0.08	NC	●	●	NC	○	●
Taurus	1994	0.25	0.80	0.09	NC	◓	NC	●	○	◓

○ Large emissions decrease (>50%)

◒ Moderate emissions decrease (10%–50%)

◓ Moderate emissions increase (10%–50%)

● Large emissions increase (>50%)

NC = No change (i.e., less than 10%)

on reformulated gasoline after conversion. This indicates that either the kit or the installation had a negative impact on gasoline emissions performance. This is an area of concern for conversion systems, but at this point the test sample size is too small to make general conclusions. Additional testing, designed to further investigate this problem, is planned in 1996.

It should be noted that the liquefied petroleum gas conversion kit is of a substantially different design than the compressed natural gas kit. It is therefore impossible in this program to make any comparisons between compressed natural gas and liquefied petroleum gas fuel, even if both tests were done on the same make and model of vehicle.

The emissions comparison between reformulated gasoline and the alternative fuel in these conversions is not promising. Six of the nine vehicles converted in Maryland recorded substantial increases in oxides of nitrogen when tested on compressed natural gas, and five of nine recorded substantial increases in carbon monoxide when tested on compressed natural gas, relative to the corresponding levels obtained in the tests on reformulated gasoline. Seven of the nine Maryland vehicles achieved a decrease in non-methane hydrocarbon emissions when tested on compressed natural gas, relative to the values obtained in tests on reformulated gasoline.

In the case of the vehicles converted and tested in Denver, all those converted to compressed natural gas exhibited a small decrease in oxides of nitrogen, a substantial decrease in non-methane hydrocarbon emissions, and a substantial increase in carbon monoxide emissions when tested on compressed natural gas relative to the corresponding values obtained in tests on reformulated gasoline.

Two of the three liquefied petroleum gas conversions in Denver showed no change in oxides of nitrogen, and all three showed a substantial decrease in carbon monoxide, and a substantial increase in non-methane hydrocarbon emissions when tested on liquefied petroleum gas relative

Emissions Standards for Aftermarket Conversions

In 1974, the U.S. Environmental Protection Agency issued Mobile Source Enforcement Memorandum No. 1A, which states the agency's interim policy with regard to enforcing the "tampering" prohibition of the Clean Air Act. The primary objective of this memorandum was to ensure unimpaired emission control of motor vehicles throughout their useful lives. This memorandum, in effect, states that aftermarket conversion of vehicles to an alternative fuel will not be considered "tampering" if the installer has a "reasonable basis" for knowing that such modifications will not adversely affect emissions performance. As a result of increased aftermarket conversion activity, an additional fact sheet was issued by the Environmental Protection Agency on March 4, 1993, stating that a "reasonable basis" may include certificaton of the conversion kit by the California Air Resources Board, the Colorado Department of Health (for high-altitude areas), or by performing other Federally-recognized test procedures. All vehicles included in the Federal conversion program were required to conform to these criteria.

In 1994, the Environmental Protection Agency established new certification standards for aftermarket conversions. In order for a conversion to count as a "clean fuel vehicle" and be eligible for the Environmental Protection Agency's fleet program, or for a state to claim emissions benefits, the converter must certify the converted vehicle to these new standards. Vehicles can still be converted under Memorandum 1A, but they cannot then be used for claiming emissions benefits. The Energy Policy Act does not require that a conversion meet these new certification standards to be counted as an alternative fuel vehicle.

to the corresponding values obtained in tests on reformulated gasoline.

The results from this study cannot be considered comprehensive or conclusive because of the limited number and types of vehicles tested, especially for liquefied petroleum gas. However, a trend has been established for vehicles converted to compressed natural gas. Typically, they exhibit an emissions benefit in terms of non-methane hydrocarbons, but they tend to realize substantial increases in either oxides of nitrogen or carbon monoxide. Substantial decreases in non-methane hydrocarbons are to be expected for compressed natural gas vehicles, because the total hydrocarbons in the exhaust are composed of at least 90 percent to 95 percent methane. Too few liquefied petroleum gas conversions have been tested to establish a trend, but the initial testing has highlighted two areas of concern. The first is the emissions performance on gasoline after conversion, and the second is the increase in non-methane hydrocarbons when tested on liquefied petroleum gas after conversion.

These early emissions results for aftermarket conversions, when contrasted with the considerable emissions improvements obtained with dedicated compressed natural gas vehicles from the original equipment manufacturers (see the discussions on light-duty vehicle emissions, pages 20–28), highlight the need to consider both the fuel and the vehicle technology when evaluating options for reducing air pollution. Although using dedicated compressed natural gas vehicles from the original equipment manufacturers, for example, yields substantial emissions benefits, it cannot be assumed that all fuel system technologies will achieve this end. The aftermarket conversion vehicles that have been emissions tested so far will continue to be monitored, and the need for additional testing or the inclusion of additional vehicles will be evaluated.

Summary

Aftermarket conversions can play an important role in the transition to more widespread use of alternative fuel vehicles. However, the disappointing emissions performance of these relatively advanced closed-loop feedback kits to date raises the question of their overall contribution to reducing emissions. In addition, many less advanced and less expensive kits exist, and the technical literature confirms that they generally exhibit worse emissions performance.

Nonetheless, conversions currently dominate the alternative fuel market. Even with increasing model availability from original equipment manufacturers, many conversion strategies involve significant price advantages, which may eventually delay expansion of the original equipment manufacturer market.

Safety

Safety Incidents

In general, the overall Federal demonstration fleet continues to experience a very good safety record. Safety issues related to alternative fuels or the alternative fuel systems have very rarely been raised. In 1994, there were two serious incidents involving Chevrolet C2500 dedicated compressed natural gas pickup trucks. High-pressure fuel tanks failed on both vehicles, resulting in equipment loss, but no one was seriously injured. Neither vehicle was part of the General Services Administration fleet or included in the Federal demonstration program. The Chevrolet C2500 vehicles have all been removed from the General Services Administration fleet, and Chevrolet no longer sells this vehicle. Details of this incident were reported last year.

Two new safety incidents occurred in 1995. Both were related to compressed natural gas fuel tanks. The first was much less serious than the 1994 incident. Damage was discovered on the under-vehicle fuel tank on two compressed natural gas Dodge Ram vans during the incoming vehicle inspection, which is routinely conducted before scheduled vehicle emissions testing. The damaged tanks were emptied and tank valves were closed to isolate the tank before any tests were conducted. The fleet manager at the military base where the vehicles were operating was notified of the problem, and inspectors recommended that the tanks be thoroughly inspected and replaced if necessary. No one was injured and the vehicle was not damaged.

In the other safety incident reported during 1995, compressed natural gas pressure relief devices made by Mirada Controls failed. This device has been used on a variety of compressed natural gas vehicles, including transit buses. The device failure can result in sudden release of the compressed natural gas stored in the fuel tank. The potential for damage, including fire, depends on the presence of an ignition source and other circumstances.

Approximately 100 of these valves have failed on buses operated in the United States during the past two years. However, none of these vehicles is included in the Federal demonstration program.

To date, the incidents noted above have resulted in minimal property damage and no personal injury. The National Highway Traffic Safety Administration has issued a safety recall for the Mirada pressure relief device manufactured between June 1991 and February 1993. In addition, the Natural Gas Vehicle Coalition

Technical Committee is conducting research in areas of pressure relief device design and high-pressure compressed natural gas discharge behavior, and recommendations for improvements are expected to be forthcoming.

Infrastructure Support

To meet the demands that the increasing numbers of alternative fuel vehicles are placing 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 the components of the alternative fuel industry together. Growth of this infrastructure has been stimulated by various legislative 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). Also, the U.S. Department of Energy has promoted infrastructure development within the context of its Clean Cities Program

Refueling Sites

Expanded development of refueling sites faces a number of hurdles, depending on the alternative fuel of interest. For methanol and ethanol refueling stations, it is relatively easy to install a new in-ground or above-ground fuel storage tank. Special attention must be given to the choice of materials used to make the tank, pump, and hoses, however, because alcohol fuels are highly corrosive.

For compressed natural gas, there is a variety of refueling technology from which to choose. However, all such options are more expensive than those for alcohol fuels. A slow-fill system uses a small compressor and has the lowest cost. With this kind of arrangement, vehicles are usually attached to a refueling hose overnight, with the typical refueling time being about eight hours. A fast-fill system, on the other hand, requires a large and expensive compressor station. Using this kind of a system, a vehicle can typically be refilled 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, but they can cost $200,000 to $300,000 to build.

The absence of consistent zoning and safety ordinances continues to hamper the installation of alternative fuel refueling stations. Because each municipality has its own unique requirements, equipment and installation procedures cannot be standardized, which, in turn, leads to higher costs.

Light-Duty Vehicles

Despite the above considerations, the total number of alternative fuel refueling stations continues to increase. The percentage distribution of compressed natural gas, methanol, and ethanol refueling sites in the United States is illustrated in Figure 44. As of August 1, 1995, there were more than 1,100 compressed natural gas stations, as well as 88 methanol stations, and 36 ethanol stations. Figure 45 shows the geographic distribution of all these stations throughout the country. About two-thirds of the methanol stations are in California.

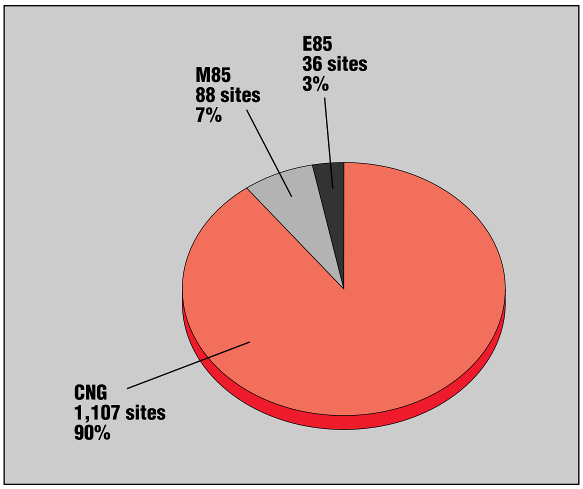


Figure 44. Compressed natural gas, methanol, and ethanol refueling sites (as of August 1, 1995)

The total number of refueling sites for alternative fuels has more than quadrupled in the past five years. Although the number of ethanol and methanol refueling sites did not expand in the past year, the number of compressed natural gas sites, according to the American Gas Association, grew at a rate of three to four stations per week. The total number of operational compressed natural gas stations reported by the American Gas Association is 1,107, representing a growth of almost 20 percent in one year. Of these sites, about three-fifths are open to the public, either with full access or access by arrangement.

A 1992 survey by the National Propane Gas Association reported 3,300 liquefied petroleum gas sites in the United states that offer propane as a motor fuel. However, the Liquefied Petroleum Gas Clean Fuels Coalition recently estimated that there are now as many as 11,000 sites where propane can be obtained for this purpose.

Transit Buses and Heavy-Duty Vehicles

Transit bus agencies and heavy-duty fleet operators generally install their own fueling stations and do not use public facilities. Regardless of the fuel in question, installing an alternative fuel refueling facility poses unique challenges in terms of setup costs and safety.

Maintenance Facilities

The General Services Administration reports that, as a rule, alternative fuel vehicle maintenance was sometimes difficult in the early years of the program (1991–1992), but is no longer the problem it once was. Although this trend does not alleviate the need for adequate maintenance facilities and qualified service personnel, it relieves the pressure to provide large numbers of garages and technicians dedicated solely to the repair of alternative fuel vehicles.

Light-Duty Vehicles

In light of the above comments, original equipment manufacturer dealerships have been retained to perform all maintenance on light-duty alternative fuel vehicles in the Federal demonstration program, using facilities and staff already in place. Personnel from each dealership has been factory-trained to service the specific alternative fuel vehicles sold by that dealership. These individuals are particularly knowledgeable about the vehicle’s fuel system and electronics, allowing the dealerships to provide reasonable service for a fair price.

Conversions

Maintaining light-duty aftermarket conversion vehicles is a bit more problematic. The conversion vehicles in the Federal demonstration program are returned to their respective

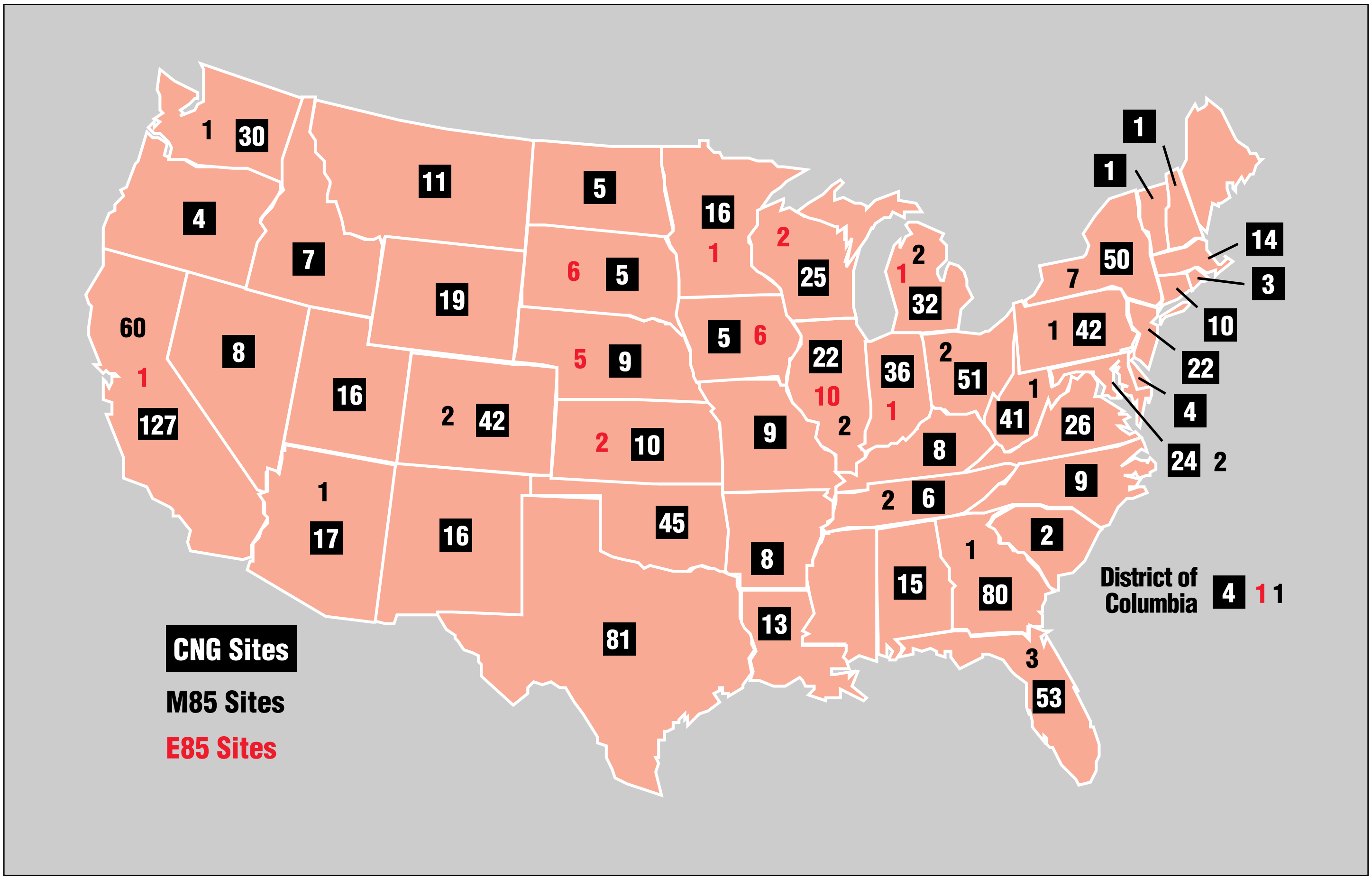


Figure 45. Geographic distribution of alcohol and compressed natural gas refining sites across the country

shops for service. In general, though, there are not currently enough qualified technicians to staff the demand. To expand this pool, the U.S. 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 automobile manufacturing, education, certification, alternative fuels production, vehicle conversions, automotive service, and the public. It is expected to provide the guidance and resources necessary to stimulate the certification program's development, implementation, and evaluation.

Transit Buses and Heavy-Duty Vehicles

Expanding the availability of maintenance facilities for alternative fuel transit buses and heavy-duty vehicles encompasses two somewhat divergent scenarios. With regard to buses, a transit agency generally performs its own maintenance on the alternative fuel vehicles it operates, or it relies on an engine dealership to do so. This is true for all the transit agencies with vehicles in the Federal demonstration program. Because a transit agency usually has only one or two central sites for maintaining its entire fleet, those sites must be outfitted for the alternative fuels, and for diesel, used by the agency. The agencies' technicians are dual-trained to quickly repair diesel and alternative fuel systems, or they gain on-the-job experience with the alternative fuel technology through repeated exposure to many vehicles. The fact that there are many vehicles involved is the key factor that makes the provision of maintenance facilities economically valid.

In contrast, there are often only a few alternative fuel heavy-duty vehicles at any given site, where the lack of maintenance technicians having experience in alternative fuel technologies is a problem. In addition, many of the maintenance shops frequented by heavy-duty vehicles do not have adequate ventilation, or sufficient detection devices to safely accommodate gaseous fuels indoors. Although both situations are improving, progress is slow. Few maintenance facilities can justify upgrading their equipment and training their personnel to service alternative fuel vehicles when the total pool of such vehicles in a given location is so small (perhaps fewer than ten).

Vehicle Storage

Although storing alcohol vehicles presents no particular problem, special precautions must be taken before housing gaseous fuel vehicles indoors. Indoor storage requires gas detectors and adequate ventilation systems. For this reason, many underground parking facilities do not permit compressed natural gas or liquefied petroleum gas vehicles to be left on their premises. 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 propane are to gain widespread use in this type of service.

Where We Are

The infrastructure for light-duty alternative fuel vehicles is growing at a pace that parallels the number of alternative fuel vehicles being deployed. No significant impediment to further expansion is evident. The infrastructure for alternative fuel transit buses is also expanding in concert with the number of those vehicles being deployed.

On the other hand, there have been significant infrastructure problems associated with the use of alternative fuels in large trucks. As an example, the operators of almost every large truck in the Federal demonstration program have encountered problems with some aspect of refueling, maintenance, or storage. The reported problems range from inconsistencies in biodiesel blending to incompatible connectors for liquefied natural gas refueling. Nonetheless, the knowledge gained in addressing such problems helps advance the use of alternative fuels in heavy-duty applications, and progress is being made on several fronts.

Vehicle Availability

Alternative Fuel Vehicles in Use

The number of light-duty alternative fuel vehicles operating in U.S. Federal and non-Federal fleets has increased steadily over the past several years. Figures 46, 47, and 48 depict the growth in deployment of these vehicles since 1992. These same figures include projections of the totals that will be in service by the end of 1996. The projections have been developed by the U.S. Department of Energy's Energy Information Administration using automotive industry sources and fleet vehicle acquisition estimates. Although not reflected in Figure 48, the Energy Information Administration projects an increase in ethanol flexible-fuel vehicles to nearly 32,000 units in the near future because of an announcement that Chevrolet will manufacture an ethanol-compatible pickup truck.

Light-duty vehicles fueled by liquefied petroleum gas (propane) are estimated to be the largest group of vehicles in the United States operating on a fuel other than gasoline. Nearly all the propane vehicles are conversions, making it difficult to determine their numbers. However, the best information currently available puts the total at approximately 217,000 units.

In January 1995, a survey of transit bus agencies was conducted by the American Public Transit Association. The results indicated an increase in the number of alternative fuel transit buses in service in 1995 compared to the number in service in 1994. Of more than 52,000 transit buses

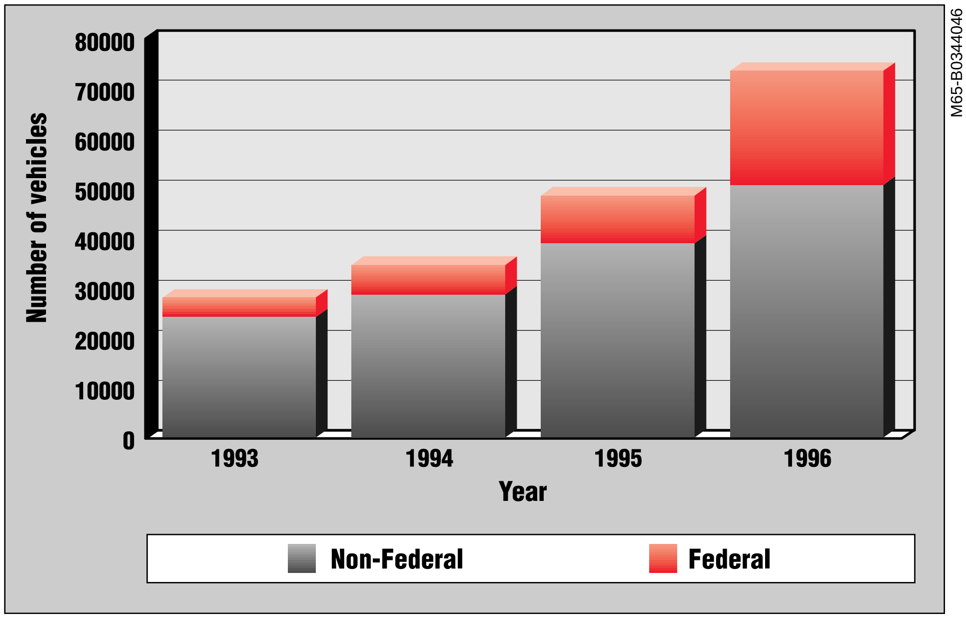


Figure 46. Number of compressed natural gas vehicles in U.S. fleets

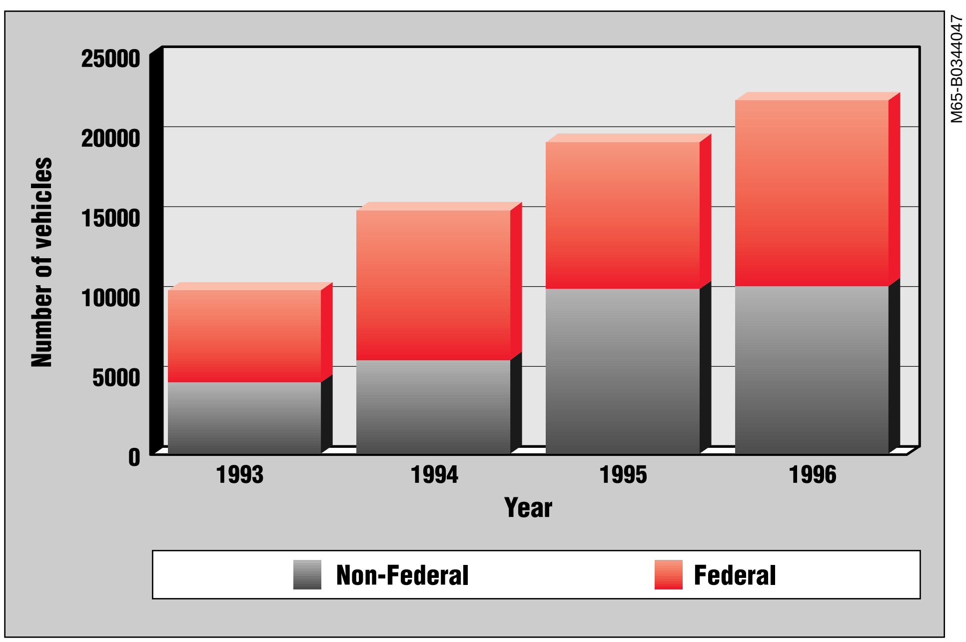


Figure 47. Number of methanol (M85) vehicles in U.S. fleets

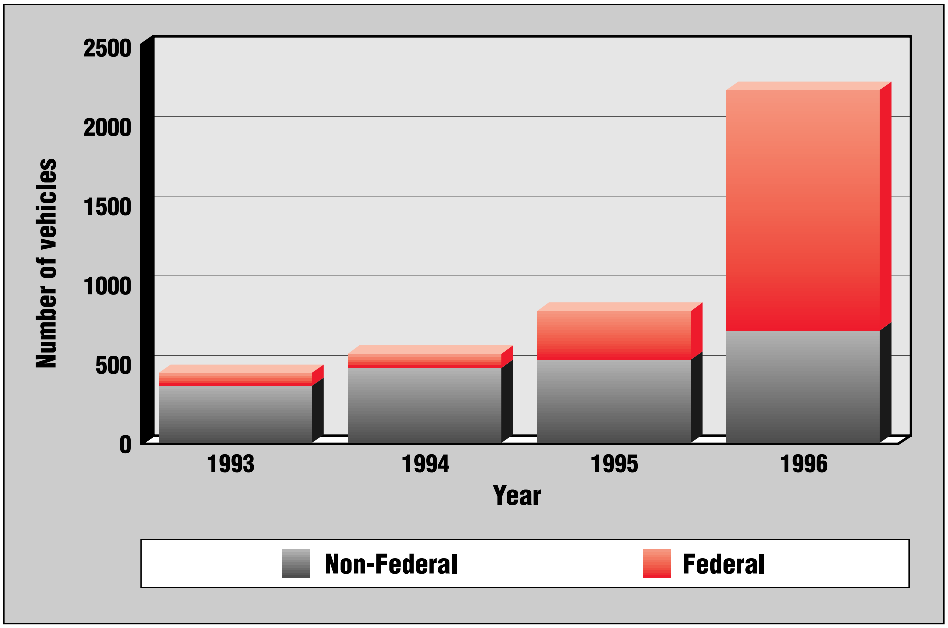


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Figure 48. Number of ethanol (E85) vehicles in U.S. fleets

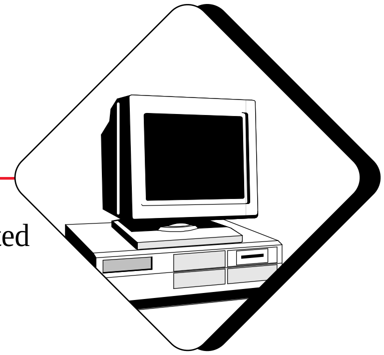
currently in operation around the country, about 5 percent of them now operate on alternative fuels. The market penetration of alternative fuels in the transit bus sector is substantially ahead of the corresponding level for any other transportation sector—a situation that may reflect the nearly ideal characteristics of transit buses as applications for alternative fuels.

Model Availability

In 1995, the manufacturers offered six compressed natural gas models (including dedicated minivans, pickups, a dedicated van, a bi-fuel van, and a bi-fuel pickup), two 85 percent methanol flexible-fuel sedans, one 85 percent ethanol flexible-fuel sedan, and one liquefied petroleum gas medium-duty truck. The models available in 1996 will include one 85 percent methanol sedan, one 85 percent ethanol sedan, six compressed natural gas vehicles (including dedicated minivans, pickups, vans, and sedans), a bi-fuel van, a bi-fuel pickup, and one liquefied petroleum gas medium-duty truck.

The Energy Policy Act of 1992 (42 U.S.C. 13212 (a) and (b)) mandates that 25 percent of all new vehicle purchases made in 1996 by the Federal government be alternative fuel vehicles. Based on projected vehicle acquisitions, the General Services Administration will be required to purchase approximately 8,600 units. The Energy Policy Act also requires new acquisitions by state fleets and fuel provider fleets to include a certain percentage of alternative fuel vehicles. The demand for alternative fuel vehicles is expected to be high in the coming years as targeted fleets work to meet the mandated requirements.

Information Dissemination



Information dissemination is an important component of the U.S. Department of Energy's program to expand the use of alternative fuels in the United States. Accurate, timely, and readily available information can only help to hasten public acceptance and adoption of alternative fuels and alternative fuel vehicles. Programs to provide information about alternative fuels are mandated by the same Federal legislation that requires alternative fuel vehicle demonstrations and data collection activities. The legislation that requires these activities includes 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 all the information being collected through the various vehicle demonstration programs, the Office of Alternative Fuels in the U.S. Department of Energy's Office of Transportation Technologies established the Alternative Fuels Data Center at the National Renewable Energy Laboratory. This center serves as the focal point for the information collected in all the vehicle demonstration programs. The Alternative Fuels Data Center maintains information on line in computerized databases. Hard copies are available as well, and are distributed through the National Alternative Fuels Hotline (1-800-423-1DOE).

Engineers in the Alternative Fuels Data Center validate the quality of the information they receive from various sources using many computerized, statistical, and manual procedures. If the data meet these quality checks, they are loaded into a production database. If the data do not satisfy the quality standards, they are further investigated to determine whether errors exist that can be corrected, and whether procedures can be implemented to prevent similar errors in the future. Once loaded into the production database, the information is analyzed and reports are developed. All information in the

The National Alternative Fuels Hotline, the U.S. Department of Energy's primary source of information about alternative fuels

Photo courtesy of Information Resources, Inc./PIX 03315 database is made available to other researchers, private industry, and anyone else interested in the information, free of charge.

Several methods are available for accessing information in the Alternative Fuels Data Center. The primary method is via the World Wide Web on the Internet, using browser software such as Mosaic. Because this graphical user interface is very intuitive and user friendly, it is gaining wide popularity throughout industry and government. The World Wide Web facilitates access to raw data, as well as complete reports, graphics, photographs, sound, and even movies. As examples, the Alternative Fuels Data Center currently maintains maps of alternative fuel refueling sites, databases of biofuels and alternative fuels literature, and the complete texts of quarterly newsletters and many alternative fuel reports, all of which can be directly accessed via the World Wide Web at http://www.afdc.doe.gov.

Users of the Alternative Fuels Data Center may also access information by programming their own queries or using commercial data query tools. These methods are recommended for the serious researcher rather than the casual user.

In addition to direct measurements taken on vehicles (for example, emissions and fuel economy), data center personnel have established a comprehensive textual database of research and demonstration information pertaining to alternative fuels. Materials that are not copyrighted can be distributed as complete documents. Copyrighted information is maintained only in the form of literature citations. Individuals interested in obtaining these materials may call the National Alternative Fuels Hotline. (1-800-423-1DOE).

The hotline staff also maintains a large inventory of general information of interest to the public, as well as to government workers, researchers on alternative fuels, and to representatives of the supporting industries. These materials are distributed free of charge by the Hotline on request.

The Alternative Fuels Data Center is constantly producing and updating a series of publications. For example, a quarterly newsletter is published that currently has a hard copy circulation of nearly 15,000. The newsletter is also available on line.

The National Alternative Fuels Hotline is the U.S. Department of Energy's primary source of information concerning alternative fuels and related issues. Hotline operators have immediate access to all databases maintained by the Alternative Fuels Data Center, as well as to information that has not yet been placed in production. The hotline's staff can immediately answer any and all questions about alternative fuels, process requests for information, and refer callers to other data sources and organizations.

In summary, information dissemination is one of the most important facets of the U.S. Department of Energy's strategy for increasing the use and acceptance of alternative fuels. The Alternative Fuels Data Center, and its associated personnel, constantly strive to improve the quality and flow of data, and to do so with the most efficient and up-to-date means possible.

Appendix

Table A-1: Emissions Tests Completed on Light-Duty Vehicles as of August 1, 1995

Vehicle Model	Year	Model Type	Number of Vehicles	Number of Tests
Chevrolet C-2500 Pickup	1992	Dedicated CNG	5	5
	1993	Standard	2	2
Chevrolet Lumina	1991	M85 flexible-fuel	7	116
		Standard	8	25
	1992	E85 flexible-fuel	13	59
	1993	E85 flexible-fuel	12	42
		Standard	16	23
Dodge B-250 Van	1991	Dedicated CNG	2	2
	1992	Dedicated CNG	36	50
		Standard	22	25
	1994	Dedicated CNG	14	14
		Standard	25	35
Dodge Caravan (mini-van)	1994	Dedicated CNG	10	10
Dodge Intrepid	1995	M85 flexible-fuel	3	7
		Standard	8	8
Dodge Spirit	1993	M85 flexible-fuel	76	319
		Standard	72	126
Ford Econoline Van	1992	M85 flexible-fuel	13	53
	1993	M85 flexible-fuel	3	9
		Standard	18	23
Ford Taurus	1991	M85 flexible-fuel	7	89
		Standard	2	18
	1994	E85 flexible-fuel	2	4
	1995	E85 flexible-fuel	12	24
		Standard	2	2
Total			390	1090

Table A-2: 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	17	87,000
Tacoma	CNG	5	14	294,000
Peoria	E95/E93*	5	23	389,000
Minneapolis	E95	5	9	57,000
Miami	M100	5	17	193,000
New York	M100	5	0	0
St. Louis	B20**	5	10	184,000
Portland	LNG	8	0	0

* Peoria switched from E95 to E93 in March 1994 for financial reasons. Approximately 70 percent of the above mileage had been accumulated when this switch was made.

** B20 is a low-level biodiesel blend that the Department of Energy does not consider to be an alternative fuel under the provisions of the Act.

Table A-3: 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	82/27	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
New York City Department of Sanitation	CNG	Cummins L10G	Garbage packer	6/3	NREL, NYC Department of Sanitation	11/92
Illinois Dept. of Commerce and Community Affairs\ Archer Daniels Midland	E95	DDC 6V92	Line haul	4/1	NREL, Illinois	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/ LA Times	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
Trucking Research Institute/Liquid Carbonics	LNG	DDC Series 60	Line haul	3/1	NREL, Liquid Carbonics	2/95
Trucking Research Institute/Con-way Western Express	LNG	Cummins C83	City Tractor	2/1	NREL, Pacific Enterprises LNG	8/95

* Other than neat biodiesel (B100), biodiesel blends are not currently considered by the Department of Energy to be an alternative fuel under the provisions of the Act.

Table A-4: Vehicles in the Heavy-Duty 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-5: Vehicles in the Heavy-Duty 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 (not currently considered by the Department of Energy to be an alternative fuel under the provisions of the Act).

Table A-6: Vehicles in the Heavy-Duty 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		

Table A-7: Vehicles in the Heavy-Duty Program: Phase 4 School Bus and Heavy-Duty Vehicle Grants

Phase	Operating Jurisdiction	State	Number	Fuel	Vehicle Type
4 4	Chicago Syracuse	Illinois New York	3 1	LPG Natural gas hybrid	Refuse haulers School bus
4 4	Tonowanda White Plains	New York New York	1 2	CNG Ethanol	Sewer jet vactor Heavy-duty trucks
4 4 4	Berkeley Jordon/Alpine Schools Milwaukee County	California Utah Wisconsin	4 4 1	CNG CNG CNG	Heavy-duty trucks School buses 5.71 V-8 engine
4 4 4	Dane County Plano El Paso	Wisconsin Texas Texas	1 3 5	Propane Propane Propane	7.51 V-8 engine 8.31 engines Heavy-duty trucks
4 4	Maricopa County York County	Arizona S. Carolina	4 3	CNG CNG	School buses School buses

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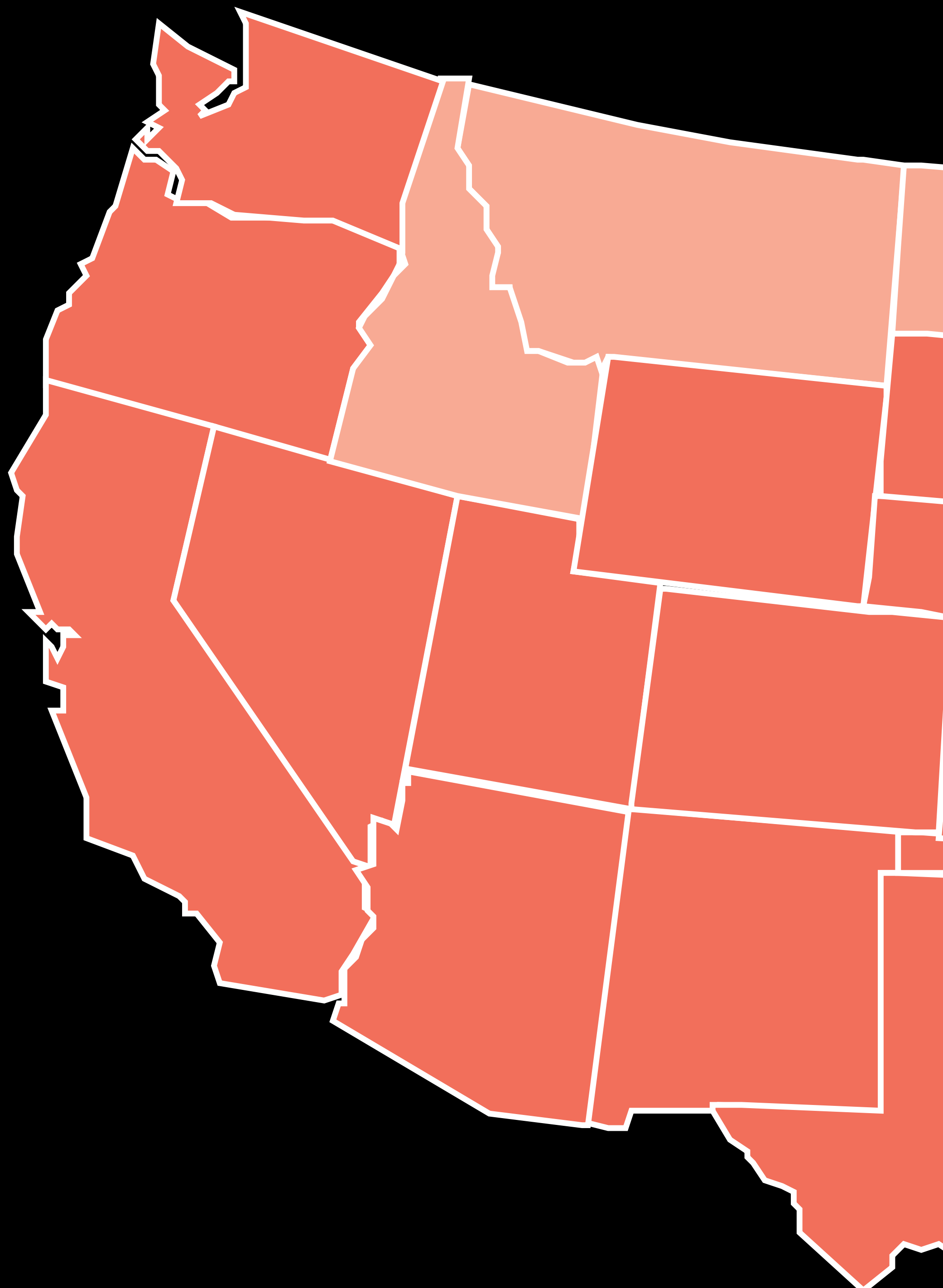

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