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Federal Alternative Motor Fuels Program-Light Duty Federal Vehicles, Trucks, and Buses

Third Annual Report to Congress for Fiscal Year 1993

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ACKNOWLEDGMENT

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

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1.0 EXECUTIVE SUMMARY

This annual report to Congress details the Federal light-duty alternative fuel vehicle operations from October 1992 through September 1993 as required by Section 400AA(b)(1)(B) of the Energy Policy and Conservation Act, 42 U.S.C. 6374(b)(1)(B). Also included are the results of the first year of the Alternative Fuels Truck Commercial Application Program and the Alternative Fuels Bus Program activities required by sections 400BB and 400CC, respectively, of the Energy Policy and Conservation Act (42 U.S.C. 6374a and 6374b). The research that is associated with these projects is coordinated by the U.S. Department of Energy (DOE), Office of Transportation Technologies, through the National Renewable Energy Laboratory (NREL).

Significant expansion of the Alternative Motor Fuels Program data collection efforts occurred during fiscal year 1993 with the addition of more alternative fuel vehicles, test sites, and Federal agency involvement. In addition, the heavy-duty and bus projects required by the Energy Policy and Conservation Act have developed to the point where data are available for reporting. Figure 1-1 illustrates the locations of the Federal light-duty, heavy-duty truck, and bus vehicles that are participating in the data collection program. Of particular note:

(1) The three years of data now available allow us to provide insight on the differences between gasoline and alternatively fueled vehicles involved in the project.

(2) The 65 alternative fuel vehicles initially acquired by the General Services Administration are nearing the end of their service life.

(3) Joint cooperation between government agencies has provided cost-effective methods for capturing vehicle performance data by using existing reporting systems at little additional cost.

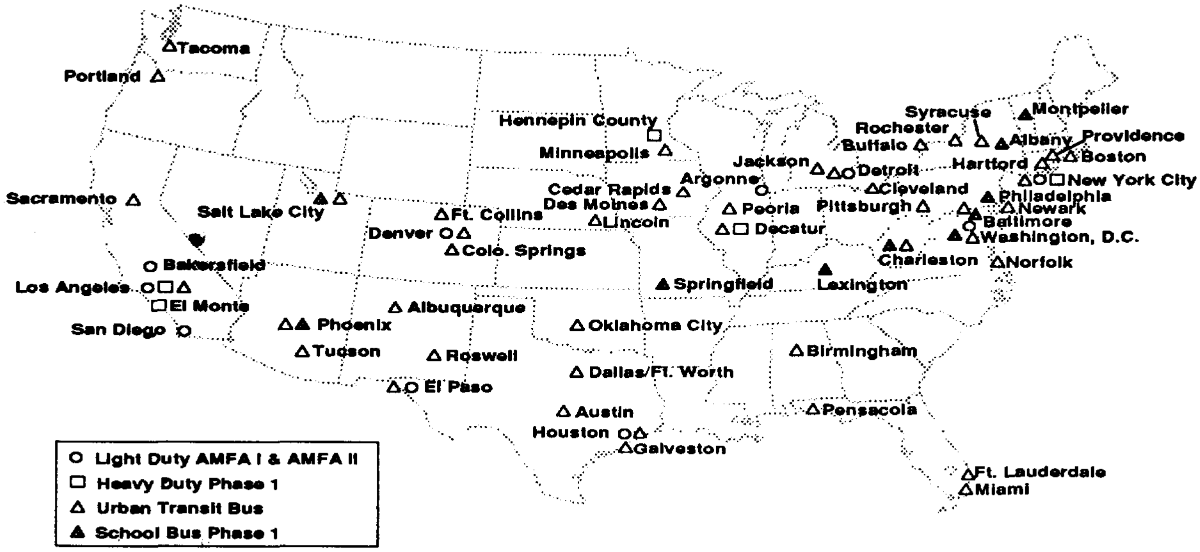
(4) The heavy-duty truck demonstration and bus projects have advanced to where meaningful data collection is now underway.

(5) The heavy-duty truck and bus projects have benefitted from a high degree of cost sharing, cost contribution, and voluntary efforts on the part of participants. Thus, Federal dollars spent on these projects have been leveraged well with other Federally funded efforts, state/local government funds, and private-sector funding, leading to significant enhancement of the utility of the information collected.

1.1 Alternative Fuel Use by Light-Duty Federal Vehicles

Through fiscal year 1993, 709 alternative fuel vehicles in the program have been procured by the General Services Administration for government operations in locations nationwide. General Motors Corporation, Ford Motor Company, and Chrysler Corporation have developed alternative fuel vehicles that are being used in these operations.

Figure 1-1. Map Illustrating Locations of Federal Light-Duty, Heavy-Duty Truck, and Bus Fleet Vehicles



Overall Light-Duty Alternative Fuel Vehicle Operation

The performance of motor vehicles is directly influenced by the driving cycles or usage patterns to which they are subjected. Therefore, operating locations have been selected (see Figure 1-1) to allow data to be collected for many varied vehicle operating conditions and usage patterns. A primary influence on vehicle performance is the climate in which these vehicles are operated. The Detroit and New York/New Jersey regions permit the evaluation of cold-weather performance, whereas the Houston region provides a warm-weather environment. Changes in altitude greatly affect the performance of motor vehicles. The Denver region vehicles, specifically, provide a means to evaluate the alternative fuel vehicles performance between high and low altitudes. Other locations with smaller fleet sizes allow for more-controlled usage. For example, the Bakersfield, California, location has only compressed natural gas vans, each of which covers 50 to 90 miles daily with a minimum of stop-and-go traffic. This can be compared and contrasted with the El Paso, Texas, location which operates compressed natural gas pickups. These vehicles average only 10 to 40 miles per day and often involve extended periods of idling and low-speed travel.

Fuel Use and Economy

Through fiscal year 1993, just over 2 million miles have been accumulated by vehicles operating at the light-duty vehicle locations identified in Figure 1-1. With more vehicles and regions joining the program by the end of 1993, large mileage accumulations are projected for fiscal year 1994. Under this project, M85 (a mixture of 85 percent methanol and 15 percent unleaded gasoline) alternative fuel vehicles have accumulated about 1,200,000 miles; compressed natural gas vehicles accumulated just over 500,000 miles; and the E85 (a mixture of 85 percent ethanol and 15 percent unleaded gasoline) vehicles have accumulated only about 40,000 miles. Total fuel consumed for fiscal year 1993 was more than 41,000 gasoline gallons equivalent of natural gas, about 20,000 gallons of M85, nearly 3,000 gallons of E85, and more than 12,000 gallons of gasoline. During fiscal year 1993, the percentage of M85 and E85 fuel consumed to total fuel consumption ranged from 95 percent to 74 percent. This means that our test vehicles are using their alternative fuels a large percentage of the time, using gasoline only when out of range of an M85 or E85 station. The M85 use is high because many of the vehicle operation sites were centralized around available M85 refueling facilities.

Fuel economy data were obtained in the laboratory as part of the Federal emissions test procedure. In addition, on-road fuel economy was obtained from the weekly vehicle data sheets completed by the vehicle operators for the Phase I vehicles. Comparison of the fuel economy reveals that for both the in-use and laboratory cases the fuel economy for M85 alternative fuel vehicles fueled with M85, when adjusted for fuel energy, was similar to the fuel economy of the M85 alternative fuel vehicles fueled with gasoline.

For both the Phase I and Phase II vehicles, on-road fuel economy data were obtained for the Ford Taurus, Chevrolet Lumina, and Dodge Spirit operating on M85; the Chevrolet Lumina operating on E85; and both the Dodge Ram 250 and Chevrolet C2500 pickup operating on compressed natural gas (CNG). Examination of the on-road fuel economies, when adjusted for fuel energy, reveals that for most of the sites the M85 alternative fuel vehicles have slightly higher fuel economy than the conventional gasoline vehicles. The exceptions to this are the Luminas in Washington, D.C., and the Tauruses in Los Angeles. Overall, the on-road fuel economies of the compressed natural gas alternative fuel vehicles, when adjusted for fuel energy, are lower than the conventional gasoline vehicles.

Emissions Testing

Since 1991, 150 emissions tests have been performed in accordance with the test procedures specified by the U.S. Environmental Protection Agency. Vehicles represented in the testing include Taurus and Lumina M85 flexible fuel vehicles operated on gasoline and M85 and standard control vehicles operated on gasoline. When examining the emissions data for the flexible fuel Taurus, it should be noted that these vehicles have not been federally certified.

Substantive emission testing of Phase II compressed natural gas vehicles started after fiscal year 1993, therefore, analysis based on these data will be presented in next year's report.

Comparison of variable fuel vehicle Luminas and flexible fuel vehicle Tauruses, when each set of vehicles was tested on Indolene test gasoline and M85, indicated that, for both fuels and vehicle types, carbon monoxide emissions increased with mileage, while unburned hydrocarbon and oxides of nitrogen emissions were relatively constant. When tested with Indolene gasoline, control vehicles exhibited trends similar to those of the M85 Luminas when they were tested with M85: increasing carbon monoxide emissions and relatively constant unburned hydrocarbon and oxides of nitrogen emissions. Comparisons of M85 variable fuel vehicle Luminas and flexible fuel vehicle Tauruses, using M85, to their counterpart gasoline production control vehicles, showed increasing carbon monoxide emissions through 15,000 to 25,000 miles of operation for M85 vehicles. Testing of the gasoline control vehicles shows an increase of carbon monoxide emissions to 15,000 miles followed by a decreasing trend at later mileage intervals.

In all, the trends observed seem to suggest that the overall emission-related behavior of M85 and gasoline test vehicles is not unusual and is similar to the variation of trends generally observed for conventional gasoline vehicles. The variability of some of the data, and the frequency of tests which exceed the current standards, seem unusually high in a few cases, indicating that there may be other factors affecting outcomes. DOE has expanded the emissions testing and data collection effort in order to improve the confidence level for fuel-to-fuel comparisons.

Driveability/Maintenance

Vehicle driveability was recorded by the driver for each vehicle and problems were recorded on idle quality, hesitation, hard starting, stalling after starting, and pinging. Through fiscal year 1993, the driveability difficulties that occurred with the M85 Ford Taurus were largely attributed to performance degradation of various unique components of the vehicle such as the Electronic Engine Control-IV engine microprocessor, fuel-sending unit, and fuel-pressure regulator. Those that occurred with the M85 Chevrolet Luminas were largely attributed to performance degradation of the unique fuel injector and fuel pump speed-controller components. Installation of upgraded hardware and the dealer service bulletins have reduced the incidence of driveability problems.

Although driveability problems have significantly declined through extensive maintenance and vehicle-design upgrades, the number of reported driveability difficulties experienced by the M85 alternative fuel vehicles at the end of fiscal year 1993 were still greater than reported for the conventional gasoline control vehicles.

Most alternative fuel vehicles fueled by alcohol and compressed natural gas have had a higher frequency of unscheduled maintenance than their conventional gasoline counterparts. In some cases, maintenance has appeared to solve or greatly reduce many driveability problems. In other cases, the maintenance may have only marginally corrected the driveability difficulty, prompting the vehicle operator to continue operations and "just live with the problem." The addition of new vehicles in fiscal year 1993 has highlighted a number of challenges that face owners and operators of these vehicles. For example, the M85 Dodge Spirit vehicles were to begin operations in fiscal year 1992, but the start of these operations was delayed due to a problem with the fuel sensor that measures the relative proportions of methanol and gasoline.

Future Light-Duty Vehicle Activities

Vehicle performance and cost comparisons will continue to be generated and presented in future annual reports. As additional vehicle performance and cost data become available, progressively more comprehensive comparisons will be presented. Lifecycle cost comparisons will be conducted following the disposal of a significant number of program vehicles. Analysis methods which will be used to conduct lifecycle cost comparisons will include factors such as vehicle purchase price, operating costs (over the mission profile of the vehicle), operation efficiencies (e.g. lost productivity due to increased time for CNG refueling or extended service periods), and vehicle resale value.

Additional alternative fuel vehicle acquisitions are planned for the light-duty vehicle operations Program in fiscal year 1994, to be procured as part of a third phase of the Alternative Motor Fuels Program. Like the previous Phase I and Phase II projects, this project will be supported with full data collection and technical support services. An emissions test plan has been developed for expanding the testing of the exhaust and evaporative emissions of the light-duty vehicle fleet.

1.2 Alternative Fuels Truck Commercial Applications Program

Five alternative fuel medium- and heavy-duty vehicle projects are currently operating in California, Illinois, Minnesota, and New York. These involve 97 alternative-fueled vehicles and 33 control vehicles, for a total of 130 vehicles, including line-haul tractors, refuse hauler trucks, snowplow/dump truck maintenance vehicles, and delivery vans. These vehicles are operated by Vons Grocery Co., Archer Daniels Midland Company, the New York City Department of Sanitation, Hennepin County (Minnesota), and the Federal Express Corporation. The alternative fuels currently being used by the heavy-duty vehicles include compressed natural gas and ethanol (E95, a mixture of 95 percent ethanol and five percent unleaded gasoline). The alternative fuels being evaluated in the medium-duty vehicles are compressed natural gas, electricity, M85, propane, and reformulated gasoline.

Overall Vehicle Operations

Mileage accumulation data are being collected for all of the heavy-duty projects and data analysis is underway. The total accumulated miles for the Federal Express project from initiation through September 1993 were nearly 1,500,000 miles. The New York City Department of Sanitation project has accumulated over 20,000 miles in fiscal year 1993 with six compressed natural gas trucks. For the Archer Daniels Midland project, 662,261 miles have been accumulated on four vehicles that operate on E95 and on one diesel control vehicle.

Fuel Use and Economy

Overall fuel economy for the alternative fuel vehicles, expressed as miles per gasoline gallon equivalent, or miles per diesel gallon equivalent, were comparable to their gasoline or diesel vehicle counterparts. Although alternative formulations achieved slightly lower miles per gallon equivalent relative to traditional fuels, there are some mitigating factors that hold promise for improved performance. Engine development, for example, is highly refined for diesel engines, which have been modified over many decades of use, whereas ethanol engines are being tested for the first time in some instances. In addition, there are differences in the technology of ethanol/methanol engines that require different throttling; compressed natural gas tanks are presently heavy compared to gasoline tanks, offsetting expected gains; and the newer alternative fuel engines have undergone less development and, as a result, are less optimized than their counterparts. Overall, however, the largest fuel economy difference was only an eight percent lower diesel gallon equivalent fuel economy for ethanol vehicles as compared to diesel vehicles in the Archer Daniels Midland line-haul tractors. Other projects showed much smaller differences or, in some cases, small advantages for the alternative fuels.

Emissions

Emissions data are still being collected and show mixed results on the small samples collected to date. Where emissions are higher than expected, valuable insight is gained into the need for further development of the engines. As an example, Archer Daniels Midland ethanol trucks had oxide of nitrogen (NO_x) emissions that were lower than those for the diesel control vehicle, as would be expected. The organic material hydrocarbon equivalent (OMHCE) emissions from the ethanol engine were significantly higher than the hydrocarbon emissions from the diesel control vehicles. It should be noted, however, that ethanol hydrocarbon emissions are generally less reactive and less toxic than the equivalent amount of hydrocarbon emissions from diesel fuel. The emissions of aldehydes and unburned ethanol for the ethanol trucks were extremely high, indicating that catalytic converter development might be needed to control such emissions.

Maintenance and Reliability

Maintenance and reliability data are being collected on all of the heavy-duty truck projects and will be provided in future reports. Durability of the alternative-fuel engines will be assessed and reported at the end of the demonstration projects. In the Federal Express project, oil consumption is being reported by Federal Express employees, and oil samples are being collected for chemical analysis with each oil change. As of September 30, 1993, a total of 421 oil samples had been analyzed. Nearly all of the vehicles have had at least four oil changes.

For the Federal Express project, engine durability will be assessed at the end of the demonstration, with detailed inspections of two disassembled engines from each fleet location.

Future Activities

Several new truck demonstration projects will begin in the near future. One will begin operations in Hennepin County, Minnesota, and will operate on E95. Two ethanol heavy-duty road maintenance and truck/snowplows will begin operating with the State of Nebraska Department of Public Roads. The United Parcel Service will begin operating compressed natural gas-powered package vehicles in the near future. These projects account for a total of 25 alternative fuel vehicles. Several compressed natural gas vehicle projects are also planned for operation in California and will be set up by Acurex Environmental Corporation with cooperation from a number of host sites.

The Trucking Research Institute is actively working toward bringing several other commercial alternative fuel heavy-duty projects into operation. These projects include seven original equipment manufacturer heavy-duty refuse vehicles operating on liquefied natural gas vehicles manufactured by Mack Trucks, Inc.; a city delivery heavy-duty project in Southern California using a liquefied natural gas vehicle manufactured by Ford Motor Company; a soy diesel (biodiesel) project using heavy-duty trucks with a variety of engines engaged in agricultural commodity hauling in Iowa and South Dakota; a heavy-duty project using liquefied natural gas-powered trucks in Louisiana; heavy duty compressed natural gas powered vehicles in the Boston Metropolitan area; and urban pickup and delivery by food-product and utility companies vehicles using medium-duty Ford F-700 vehicles with compressed natural gas engines.

1.3 Alternative Fuels Bus Program

The Alternative Fuels Bus Program includes transit buses as well as school buses. Data are being collected on alternative fuel and diesel control buses from two separate transit bus programs. Emissions and fuel economy measurements are being collected using the Transportable Engine Emissions Testing Laboratory, which was developed by West Virginia University. This mobile laboratory records emission data for major vehicle pollutants during transient and steady-state chassis dynamometer tests on both medium- and heavy-duty vehicles. The first project, sponsored by DOE, involves the collection of detailed operational, maintenance, and emissions data from six carefully selected local transit agencies across the United States. The second part of the project, sponsored by the U.S. Department of Transportation's Federal Transit Authority, provides a more general data base on most of the alternative fuel transit buses in service throughout the United States.

In the DOE bus project, a total of 78 transit buses are operating at 5 locations, with a biodiesel demonstration being set up in St. Louis, Missouri. Of the 78 buses already operating, five are operating on pure methanol (M100), 10 are operating on E95, 10 are operating on compressed natural gas, 10 on liquified natural gas, 13 are diesel buses equipped with particulate traps, and 30 are diesel control buses. In the Federal Transit Authority's alternative fuel bus project, 1,163 alternative fuel buses are in service at various locations across the country, with data collected by the owners/sponsors of each individual project.

Transit Bus Operations

Results were obtained for buses running on compressed natural gas, liquefied natural gas, E95, and M100 tested in the DOE project (Tacoma, Washington; Houston, Texas; Miami, Florida; Minneapolis, Minnesota; and Peoria, Illinois); and M100 (Riverside, California).

Fuel Use/Economy—A number of projects around the United States are evaluating methanol as an alternative fuel for transit bus applications. As an example, the Riverside (California) Transit Agency is currently operating three methanol buses and three diesel control buses in an alternative fuels demonstration project.

The average on-road fuel economy of the methanol buses in Riverside, California, on an equal energy basis, was 3.38 miles per gallon, as compared to 3.62 miles per gallon for the diesel controls. During emissions testing, however, the methanol bus tested for emissions gave slightly higher diesel gallon equivalent fuel economy (on an equal-energy basis) than the diesel bus tested.

The diesel gallon equivalent fuel economy for E95-fueled buses, operated by the Greater Peoria Mass Transit District was comparable to the diesel control buses. The ethanol buses perform similarly in terms of exhaust emissions to the diesel control vehicles, with the exception of unburned ethanol and aldehydes.

On-road fuel economy data from five transit authority projects indicate that the diesel gallon equivalent fuel economy of compressed natural gas buses can range from 70 percent to 98 percent of that for conventional diesel buses, depending on the operational duty cycle.

Emissions—In laboratory tests of emissions, methanol showed lower emissions than diesel including emissions of oxides of nitrogen, organic material hydrocarbon equivalent, carbon dioxide, and particulates.

Total hydrocarbon emissions from natural gas buses varied around the level seen in diesel vehicles, but are composed largely of methane, which is essentially unreactive in atmospheric reactions that produce photochemical smog. The carbon monoxide emissions, oxides of nitrogen emissions, and particulate emissions from the two compressed natural gas buses were significantly lower than those for the diesel control vehicles.

The carbon monoxide and hydrocarbon emissions for the pilot injection natural gas engines were significantly higher than those for the diesel control vehicles. Oxides of nitrogen emissions were fairly consistent across the range of engines. Particulate emissions for the pilot injection engines were nearly the same as those for the diesel control vehicles, even though the majority of the fuel consumed during the driving cycle is natural gas.

Carbon monoxide and oxides of nitrogen emissions were somewhat lower for the ethanol buses than for the diesel control buses. On the other hand, the hydrocarbon emissions for the ethanol buses were substantially higher than for the diesel control buses. The emissions results show that the particulate emissions from the ethanol buses were higher than those from the diesel control vehicles (equipped with particulate traps). The ethanol and aldehyde emissions from the ethanol engines were quite high, as expected, because these vehicles were not equipped with catalytic converters.

Maintenance—The overall cost per mile ($0.57) of the methanol buses is more than twice that of the diesel buses ($0.21). The most significant difference in costs are related to labor, repair parts, and higher cost of the methanol fuel. The increased number of road calls for the methanol buses is indicative of more failures on the road for these buses, but the uptime was still greater than 90 percent. It should be noted that the technology used for these buses is more than 3 years old, and subsequent improvements in design, many based on operating data, have been realized.

Future Transit Bus Activities—Phase I of the Alternative Fuels Bus Program was structured to gain basic information from the existing bus demonstrations which are being managed by the U.S. Department of Transportation. A more focused Phase II project has been initiated by DOE to gather more detailed data with limited numbers of alternative fuel buses from selected transit authorities. Data collection and analysis will continue on current and new projects.

School Bus Operations

In addition to the transit buses, DOE is providing incentives and assisting various school districts around the country in setting up alternative fuel demonstration vehicles. There were five buses in operation during fiscal year 1993 in Wood County, West Virginia, and Shenendehowa Central School District, New York. The total mileage accumulation for these five buses as of September 1993 was 30,125 miles. Four of the school buses used compressed natural gas with Hercules natural gas engines, and one bus used a Chevrolet gasoline engine converted to natural gas with an aftermarket conversion kit. Also included was a modified diesel engine with an aftermarket natural gas fumigation system, along with gasoline and diesel control school buses.

Results from the emissions tests varied over a wide range for the different fuel systems. This illustrates the difficulty with many aftermarket natural gas conversion systems. If the proper equipment is not available to calibrate the engine air-fuel ratio when setting up the system, emissions can be extremely high. The existing data indicate that significant engine development work is required on natural gas conversions if natural gas is to be a viable alternative fuel option for school bus applications.

Future School Bus Activities—Eleven localities have received grants for original equipment manufacturer alternative fuel school buses, with two operating as above, and nine others about to begin. Ten of these projects will be fueled with compressed natural gas and one will be fueled with methanol. There are plans for Phase II grants which would add 16 new school bus projects.

1.4 Safety

Safety experience was based on information collected from communications with drivers involved in accidents, discussions with fleet managers, and queries of the General Services Administration data on these vehicles through September 1993. Examination of the National Highway Traffic Safety Administration manufacturer recall data base and discussions directly with vehicle manufacturers revealed the following safety-related recalls or no-cost warranty actions specifically targeted toward alternative fuel and electric vehicles:

- The 1992 Chevrolet Lumina with the methanol/ethanol fuel system was recalled for fuel leakage. These vehicles were returned to the dealers and the fuel tanks were replaced.

- The Alternative Motor Fuels M85 Dodge Spirits were not allowed to go into service due to a leaking fuel sensor. These vehicles were returned to the dealers and the fuel sensors were replaced.

During the third quarter of 1993, one Federal Express vehicle had a fire while operating on M85. The fire started near the cold-start injector, most likely from a fuel leak. No personal injury or damage to cargo occurred; however, there was minor damage to the engine compartment wiring.

On December 6, 1992, a Neoplan transit bus powered by a dual-fuel Detroit Diesel 6V92 pilot injection natural gas engine was damaged by a natural gas ignition. This occurred while new-vehicle inspection certification was being conducted at the Houston Metro Transit maintenance facility. No injuries resulted from this incident.

Analysis of the National Highway Traffic Safety Administration alternative fuel and electric vehicle crash file reveals only one vehicle collision in the September 1992 to September 1993 time period. This involved an electric vehicle which is not part of the current Alternative Motor Fuels Program.

Special Item

As this report was in final preparation, a significant event occurred. Two General Motors C2500 pickups running on compressed natural gas, one in California and one in Minnesota, incurred identical compressed natural gas fuel-tank ruptures, with injuries to personnel. Investigation into the cause of the fuel-tank ruptures is ongoing. However, preliminary results suggest that the tanks failed due to environmental degradation (most likely from contact with corrosive agents) of the outer composite wound reinforcement. Additional findings will be presented in future reports. Although these were not Federal vehicles, they were identical to 600 General Services Administration vehicles. The General Services Administration promptly issued orders to cease all operation of these vehicles. General Motors has recalled all of these vehicles (including the 600 Federal vehicles) and has agreed to refund the purchase price of these vehicles to the General Services Administration.

1.5 Infrastructure

The increasing number of alternative fuel vehicles is becoming a primary driving force for developing an alternative fuel vehicle refueling infrastructure. At this time, supply is not universally available, and in certain demonstrations vehicles have had to be placed in areas that have inconvenient or nonexistent alternative fuel refueling facilities. These vehicles have not achieved the usage they might have, or in the case of flexible fuel vehicles, used more gasoline than they otherwise would have. Although this is not a major factor in the operations of vehicles which are used locally, such as transit buses, that have a central refueling site, the availability of fuels themselves may be.

Title XIX of the Energy Policy Act of 1992 does provide incentives for alternative fuel refueling facilities in the form of tax deductions. Many suppliers are beginning to invest in the facilities and the necessary product development. Many of these have supplied fuels for the vehicles discussed in this report. They include ARCO, Chevron, Conoco, Exxon, Methanex, Mobil Oil Company, Shell Oil Company, and Sunoco. However, the basic hurdle to investment in alternative fuel refueling facilities remains the number of vehicles that will be served by a given facility. This issue is being addressed by DOE in other related alternative fuel infrastructure expansion efforts such as the Clean Cities Program.

Currently, M85 is being supplied by fuel companies at more than 78 public refueling facilities throughout the United States. E85 has 30 refueling sites scattered throughout the country. Compressed natural gas is being supplied by various natural gas utilities at more than 730 compressed natural gas refueling facilities in the United States. The General Services Administration has, through its placement of vehicles and through negotiations with fuel suppliers, been instrumental in getting additional alternative fuel refueling locations installed to support alternative fuel vehicle projects.

2.0 INTRODUCTION

This annual report to Congress details the third year of Federal light-duty alternative fuel vehicle operations for the period from October 1992 to September 1993, and provides additional information on the Alternative Fuels Bus Program, and Truck Commercial Application programs. The Federal light-duty vehicle operations for fiscal years 1991 and 1992 were reported in the first and second annual reports to Congress, respectively.[1,2]

The Federal Light Duty Alternative Motor Fuels Program's annual report is required by Section 400AA(b)(1)(B) of the Energy Policy and Conservation Act, 42 U.S.C. 6374(b)(1)(B). Section 400AA(b)(1) states:

> "(A) The Secretary, in cooperation with the Environmental Protection Agency and the National Highway Traffic Safety Administration, shall conduct a study of a representative sample of alternative fueled vehicles in Federal fleets, which shall at a minimum 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.
> "(B) The Secretary shall provide a report on the results of the study conducted under subparagraph (A) to the Committees on Commerce, Science, and Transportation and Governmental Affairs of the Senate, and the Committee on Energy and Commerce of the House of Representatives, within one year after the first such vehicles are acquired, and annually thereafter."

The Alternative Fuels Truck Commercial Application Program is required by Section 400BB(a) of the Energy Policy and Conservation Act, 42 U.S.C. 6374a. Section 400BB(a) states:

> "(a) Establishment.- The Secretary, in cooperation with manufacturers of heavy duty engines and with other Federal agencies, shall establish a commercial application program to study the use of alternative fuels in heavy duty trucks and, if appropriate, other heavy duty applications."

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[1]U.S. Department of Energy, Office of Transportation Technologies, *Federal Alternative Fuel Program Light-Duty Vehicle Operations - First Annual Report to Congress for Fiscal Year 1991*, DOE/CE-0351, March 1992.

[2]U.S. Department of Energy, Office of Transportation Technologies, *Federal Alternative Fuel Program Light-Duty Vehicle Operations - Second Annual Report to Congress for Fiscal Year 1992*, DOE/EE-0004, July 1993.

The Alternative Fuels Bus Program is required by Section 400CC(a) of the Energy Policy and Conservation Act, 42 U.S.C. 6374b. Section 400CC(a) states:

> "(a) Testing.- The Secretary, in cooperation with the Administrator of the Environmental Protection Agency and the Administrator of the National Highway Traffic Safety Administration, shall, beginning in the fiscal year ending September 30, 1990, assist State and local government agencies in the testing in urban settings of buses capable of operating on alternative fuels for the emissions levels, durability, safety, and fuel economy of such buses, comparing the different types with each other and with diesel powered buses, as such buses will be required to operate under Federal safety and environmental standards applicable to such buses for the model year 1991. To the extent practicable, testing assisted under this section shall apply to each of the various types of alternative fuel buses."

The Energy Policy and Conservation Act encourages the use and production of alternative fuel vehicles. The Congress has recognized that replacement of imported oil with domestically available alternative fuels will help to achieve energy security and improve air quality. In implementing this Act, the Federal government is assisting clean-burning, non-petroleum-based transportation fuels in order to achieve a threshold level of commercial application and consumer acceptability. At that time, they will successfully compete with petroleum-based transportation fuels. The objectives of the program are to demonstrate the environmental, economic, and performance characteristics of alternative fuel fleet vehicles and to provide information for engine/vehicle manufacturers and the general public.

The Energy Policy and Conservation Act directs the Department of Energy to undertake certain tasks to implement alternative fuel projects in the transportation area and to work with other Federal agencies, including the General Services Administration, the Department of Transportation, and the Environmental Protection Agency. The Energy Policy and Conservation Act provides for the cooperative efforts of State and local governments, as well as an active role for industry. In the vehicle evaluation/demonstration/testing efforts, three major activities are identified: a Federal light-duty vehicle demonstration program, a truck commercial application program, and an alternative fuels bus program. The Department has identified the National Renewable Energy Laboratory, formerly the Solar Energy Research Institute, as the field manager to support the alternative fuel evaluation/demonstration/testing efforts. Information on vehicle emissions, fuel economy/consumption, reliability, driveability, operating costs, and health/safety is currently being collected and evaluated to determine the commercial viability of alternative fuel vehicles in a fleet environment. The Alternative Fuels Data Center established at the National Renewable Energy Laboratory is responsible for managing, storing, displaying, and allowing public access to all available data on alternative fuels.

The objectives of the Alternative Fuels Data Center are to:

- Design, implement, and operate a computerized data base system for storage and retrieval of available data on alternative transportation fuel demonstration and evaluation efforts.

- Provide access via computer to external users in the scientific, industrial, and government communities.

Significant expansion of data collection efforts occurred during fiscal year 1993, with the addition of more alternative fuel vehicles, test sites, and Federal agency involvement. In addition, the heavy-duty and bus projects have developed to the point where data reporting can begin.

There has been a significant expansion in data collection, altering the format and content of this third annual report (compared to the prior annual reports). Trends have been described, using selected operational characteristics as examples.

In reviewing the remainder of this report, particularly as related to the status of fleet data collection efforts, it is important to keep the following points in mind:

(1) After nearly three years of operation, the light-duty project fleets have matured to the point where preliminary comparisons and judgments about the relative differences between gasoline and alternative-fueled vehicles can be made.

(2) The 65 alternative fuel vehicles initially acquired by the General Services Administration for the Phase I light-duty project are nearing the point at which they have completed their service life and may be replaced.

(3) Joint cooperation between government agencies has provided cost-effective methods for capturing vehicle performance data by using existing reporting systems at little additional cost.

(4) The heavy-duty truck and bus projects have evolved to a point where meaningful data collection is now underway.

(5) The heavy-duty truck and bus projects have benefitted from a high degree of cost sharing, cost contribution and voluntary efforts on the part of participants. Thus, Federal dollars spent on these projects have been leveraged very well with other Federally funded efforts, State/local government funds, and private-sector funding.

Overall, the data collection efforts are yielding the types of information that DOE believes will be useful for prospective users of alternative fuel vehicles. As more data continue to become available, more-informed judgments can be made about the benefits, limitations, and operating characteristics of alternative fuel vehicles.

The increasing number of alternative fuel vehicles in the Federal fleet are becoming a primary driving force for developing an alternative fuel vehicle refueling infrastructure. Figure 2-1 details the distribution of alternative fuel refueling locations throughout the country. Although this map shows an impressive array of alternative fuel refueling locations, there are still many locations where government alternative fuel vehicles have been placed where no existing or convenient alternative fuel refueling facilities exist. This has spurred the private sector to respond to this demand. In some cases, however, the number of alternative fuel vehicles in a fleet location remains too small to justify infrastructure investment by the private sector. As a consequence, some government alternative fuel vehicles have not achieved the usage (or in the case of flexible fuel vehicles, have used more gasoline) that they would have if alternative fuel refueling facilities had been conveniently available.

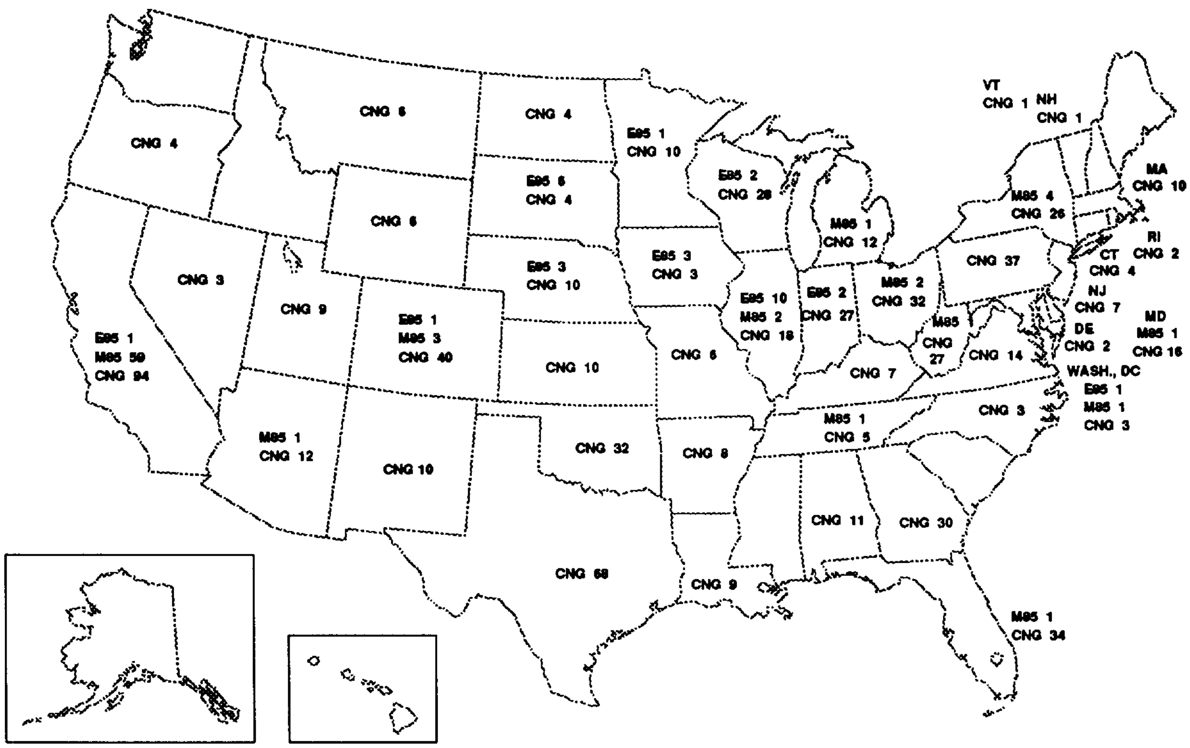
Title XIX of the Energy Policy Act of 1992 provides incentives for alternative fuel refueling facilities in the form of tax deductions. However, the basic obstacle to investment in alternative fuel refueling facilities remains the number of vehicles that will be served by a given facility. Unless private investors are given assurances that sufficient alternative fuel vehicles will become available in the near future, they will not take the risk of investing in alternative fuel refueling facilities.

2.1 Light-Duty Vehicles

The Light-Duty Alternative Motor Fuels Program is currently divided into two phases. Phase I began in 1991 with the introduction of 25 M85 (a mixture of 85 percent methanol and 15 percent unleaded gasoline) variable-fuel 1991 Chevrolet Luminas, 40 flexible-fuel 1991 Ford Tauruses, and 16 control vehicles (standard-production 1991 Luminas and standard-production 1991 Tauruses). The four initial alternative fuel vehicle fleets were located in Detroit, Michigan; Los Angeles, California; San Diego, California; and Washington, D.C. Phase II was started in 1992 with the introduction of alternative fuel vehicles in Argonne, Illinois; Bakersfield, California; Houston and El Paso, Texas; New York City, New York; Denver, Colorado; and expansion of the Washington, D.C., and Detroit Phase I sites. The number of vehicles participating in the program now include an additional 644 alternative fuel vehicles and the 286 conventional gasoline-fueled control vehicles. In the near future, there are plans for a third phase with 196 additional vehicles and one additional site in Atlanta, Georgia.

Data are being collected to evaluate the operation and cost of these vehicles relative to the gasoline control vehicles. The National Renewable Energy Laboratory are responsible for collecting and managing the data-gathering efforts. Once the data are collected and passed through quality checks, they are made available to the public through online computer access and published reports. Typical data and information being collected on this fleet include:

Figure 2-1. Location of Methanol/M85, Ethanol/E85, and Compressed Natural Gas Vehicle Refueling Sites



Source: National Renewable Energy Laboratory

- Vehicle usage and fleet characterizations.
- Inventory and analysis of alternative fuel use and refueling facility characterizations.
- Measurement and analysis of vehicle fuel use.
- Measurement and analysis of operating cost.
- Vehicle emissions performance.
- Vehicle driveability and operator satisfaction.
- Reliability and maintenance information including oil sampling and analysis.
- Sampling and analysis of fuel composition and quality.

2.2 Commercial Vehicles and Heavy-Duty Trucks

The National Renewable Energy Laboratory, located in Golden, Colorado, is the primary field laboratory responsible for the operation and data collection activities of the Alternative Fuels Truck Commercial Applications Program. Project participants in this program include the Illinois Department of Energy and Natural Resources/Archer Daniels Midland, Acurex/Vons Grocery Co., and New York Department of Sanitation.

The Trucking Research Institute, under contract to the National Renewable Energy Laboratory, serves as a focal point in the commercial trucking industry for the advancement of alternative fuel usage. Its primary responsibilities are to:

- Catalog all existing alternative fuels heavy-duty and medium-duty trucking demonstrations.

- Gather data from ongoing demonstrations.

- Provide incentives for new alternative fuel heavy-duty and medium-duty projects.

- Publicize truck-related alternative fuel information throughout the industry and government through a quarterly newsletter, and periodic industry presentations throughout the country.

Although medium-duty vehicle projects are not expressly included in the heavy-truck and commercial vehicle statute requirements, they are included in this program because their operating environment closely resembles that of their heavy-duty vehicle counterparts. While some of the vehicles share similar components to those in the light-duty projects, their specific application requires more rigorous use than their light-duty counterparts. Data generated and analyzed from these vehicles will allow DOE and potential commercial fleet operators to identify operational issues that influence the incorporation of additional medium-duty alternative fuel vehicles in both Federal and private fleets.

Five alternative fuel heavy-duty vehicle fleet projects are currently operating, involving a total of 130 vehicles with:

- The Archer Daniels Midland Company.

- Vons Grocery Company.

- The New York City Department of Sanitation.

- Hennepin County, Minnesota.

- Federal Express Corporation.

2.3 Transit and School Buses

2.3.1 Transit Buses

Two separate transit bus data collection projects are being managed by the National Renewable Energy Laboratory, under DOE sponsorship. These include data collection from the various transit bus operational sites, analysis, data storage in the Alternative Fuels Data Center, and making the data available to the industry, transit bus agencies, and other interested parties. Other participants in these projects include the Federal Transit Authority, various state and local governments, transit bus agencies, engine manufacturers, and bus manufacturers. These data are collected on alternative fuel and diesel control buses from two separate transit bus projects and stored at the Alternative Fuels Data Center.

The first project, sponsored by DOE, involves the collection of detailed operational, maintenance, and emissions data from six carefully selected transit agencies across the United States. The transit agencies were selected based on:

- The availability of new alternative fuel buses that have new original equipment manufactured engines for fuels such as compressed natural gas (CNG), liquefied natural gas (LNG), methanol (M100), and ethanol (E95).
- The availability of identically equipped control vehicles.
- Cooperation of the transit agency in supplying detailed data.

A second project is sponsored by the U.S. Department of Transportation's Federal Transit Authority and provides a more general data base on most of the alternative fuel transit buses in service throughout the United States. Data are generated on the types, quantities, locations, and mileage accumulations for all of the alternative fuel buses in service at major transit agencies across the country. DOE's role is to collect data on emissions, fuel economy, and other operational characteristics for selected alternative fuel buses and compare those data with similar data from diesel buses that are currently in service.

2.3.2 School Buses

In addition to the transit buses, DOE is coordinating, providing incentives, and assisting various school districts around the country in setting up alternative fuel demonstration vehicles. Data are generated on fuel economy, driveability, maintenance, and emissions.

In fiscal year 1992, the Department of Energy issued eleven grants to fund the incremental cost of alternative fuel school buses. This money was distributed in fiscal year 1993 with most of the school districts receiving their money and ordering the buses. Many buses were acquired over the summer and had just begun operation at the end of fiscal year 1993.

3.0 ALTERNATIVE FUEL USE BY LIGHT-DUTY FEDERAL VEHICLES

3.1 Program Participants

For light-duty vehicle operations, alternative fuel vehicles supplied by General Motors Corporation, Ford Motor Company, and Chrysler Corporation have been procured by the General Services Administration for use in the Light-Duty Alternative Motor Fuels Program. There are six vehicle models currently represented in Phase I and Phase II projects. The Dodge Spirit, Ford Taurus, Chevrolet Lumina, and Ford Econoline vans operate on M85 (a mixture of 85 percent methanol and 15 percent unleaded gasoline), or any mixture to 100 percent gasoline. Chevrolet also produces a version of the Lumina which is capable of operating on E85 (a mixture of 85 percent ethanol and 15 percent unleaded gasoline) or any mixture to 100 percent gasoline. The Dodge Ram van and Chevrolet C2500 pickup trucks operate exclusively on compressed natural gas. In addition to supplying these vehicles to General Services Administration, Ford, General Motors, and Chrysler support the program by supplying service facilities, service technician training, and replacement parts. All vehicles carry the standard warranty offered by these auto manufacturers on conventional vehicles.

As of this report, M85 is being supplied by fuel providers at 78 public refueling facilities throughout the United States. Although E85 does not have as many refueling sites as M85, there are 30 E85 refueling locations scattered throughout the country. The major fuel providers participating are: ARCO, Chevron, Conoco, Exxon, Methanex, Mobil Oil Company, Shell Oil Company, and Sun Oil Company. Compressed natural gas is being supplied by various natural gas utilities throughout the United States. Currently, there are 730 compressed natural gas refueling facilities in the United States.

The M85, E85, and compressed natural gas vehicles procured for this program by the General Services Administration are owned and managed by the Interagency Fleet Management System. These vehicles are continually being incorporated into Federal fleets throughout the United States and will continue through fiscal year 1994. The General Services Administration has also been instrumental in getting additional alternative fuel refueling locations installed to support the Light-Duty Alternative Motor Fuels Program through its placement of vehicles and through negotiations with fuel suppliers. In addition to providing the procurement and management of the light-duty alternative fuel vehicle fleet, General Services Administration also provides access to valuable vehicle maintenance and operational data through its computerized maintenance and refueling record-management centers. In addition, the local General Services Administration regions have been especially helpful to DOE/National Renewable Energy Laboratory in providing special data queries and analysis.

Most of the Federal agencies currently participating in the program are noted in Table 3-1. Participation requires the collection of data specific to vehicle performance. Data from these vehicles have been collected and analyzed by the National Renewable Energy Laboratory since 1991, with these findings being reported in the First Annual Report to

Table 3-1. Selected Federal Agencies Participating in the Federal Light-Duty Alternative Motor Fuels Program

Bureau of Indian Affairs	Department of State	National Park Service, Denver Service Center
Central Intelligence Agency	Department of Transportation	Naval Reserve Recruiting
Consumer Product Safety Commission	Department of Treasury	Office of Personnel Management
Defense Contracts Administration	Department of Veterans Affairs	Peace Corps
Defense Information Systems Agency	Environmental Protection Agency	Small Business Administration
Defense Intelligence Agency	Federal Emergency Management Agency	U.S. Air Force
Defense Logistics Agency	Federal Energy Regulatory Commission	U.S. Army
Department of Agriculture	Fish and Wildlife Service	U.S. Coast Guard
Department of Commerce	Food and Drug Administration	U.S. Customs Seaport
Department of Defense	General Services Administration	U.S. District Court
Department of Energy	Government Printing Office	U.S. Geological Survey
Department of Health and Human Services	Library of Congress	U.S. Marine Corps
Department of Housing and Urban Development	National Archives Record Administration	U.S. Military Academy
Department of Interior	National Credit Union Administration	U.S. Navy
Department of Justice	National Guard	U.S. Postal Service
Department of Labor	National Oceanic and Atmospheric Administration	U.S. Secret Service
		Veterans Administration Hospital
		Walter Reed Army Medical Hospital

in the First Annual Report to Congress for fiscal year 1991[1] and the Second Annual Report to Congress for fiscal year 1992.[2]

3.2 Vehicles/Locations

The Federal Light-Duty Alternative Motor Fuels Program is currently divided into two phases. Phase I began in 1991 with the introduction of 25 M85 variable fuel 1991 Chevrolet Luminas, 40 M85 flexible fuel 1991 Ford Tauruses, and 16 control vehicles (8 standard production 1991 Luminas and 8 standard production 1991 Tauruses). The four initial alternative fuel vehicle projects were located in Detroit, Michigan; Los Angeles and San Diego, California; and Washington, D.C. Phase II was started in 1992 with the introduction of alternative fuel vehicles in Argonne, Illinois; Bakersfield, California; El Paso and Houston, Texas; New York City, New York; Denver, Colorado; as well as expansion of the Washington, D.C., and Detroit Phase I sites. The number of vehicles participating in the program now include an additional 644 alternative fuel vehicles and 286 conventional gasoline control vehicles. Figure 3-1 and Table 3-2 outline the locations and

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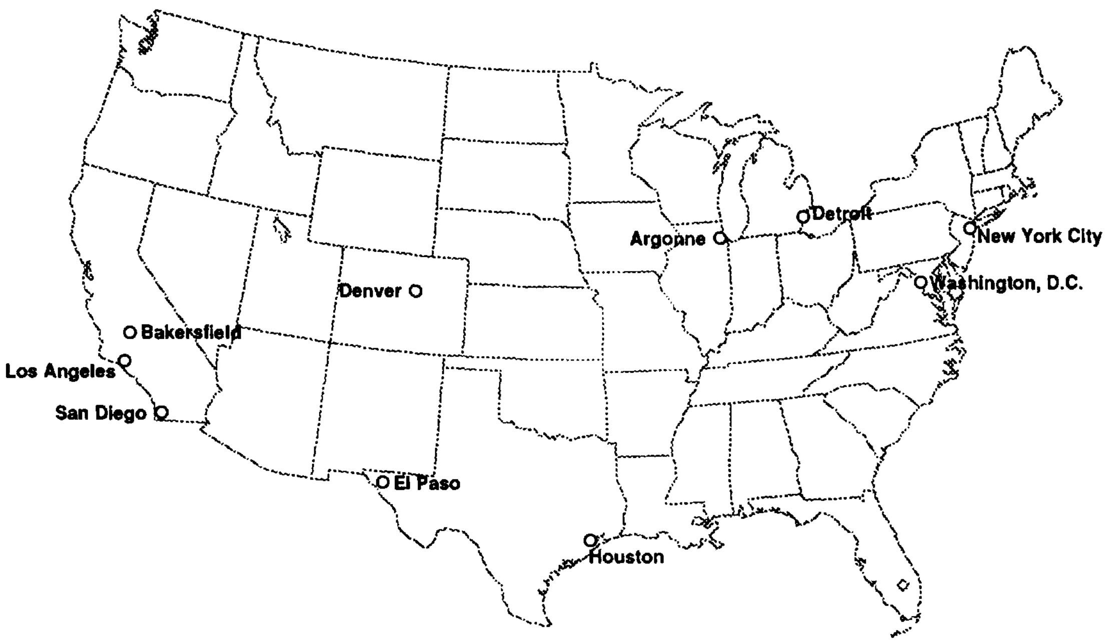
[1]U.S. Department of Energy, Office of Transportation Technologies, *Federal Alternative Fuel Program Light-Duty Vehicle Operations - First Annual Report to Congress for Fiscal Year 1991*, DOE/CE-0351, March 1992.

[2]U.S. Department of Energy, Office of Transportation Technologies, *Federal Alternative Fuel Program Light-Duty Vehicle Operations - Second Annual Report to Congress for Fiscal Year 1992*, DOE/EE-0004, July 1993.

Figure 3-1. Current Phase I and Phase II Light Duty Vehicle Locations



distributions of these vehicles. In the near future, there are plans to add 196 additional vehicles and one additional site in Atlanta, Georgia, for Phase III.

The primary criteria that General Services Administration uses in selecting locations for alternative fuel vehicles are (1) whether the location is one of the 22 non-attainment areas for poor ambient air quality under the Clean Air Act Amendments of 1990; (2) whether the location is one of the 125 metropolitan areas covered under the Environmental Protection Act; (3) alternative fuel potential availability in the location; (4) vehicle replacement needs of Federal agencies; and (5) vehicle availability from the original equipment manufacturers.

In addition to the General Services Administration criteria for location selection, DOE and the National Renewable Energy Laboratories use programmatic and vehicle operation considerations. It is less than desirable from a programmatic and efficiency viewpoint to attempt to manage and collect data from many highly dispersed vehicle locations. Therefore, vehicle locations were selected and restricted to specific major metropolitan areas or larger centralized agencies that have made an expressed commitment to participate.

Primary influences on vehicle performance are temperature and altitude in which these vehicles operate. The Phase II portion of this program added several significant

Table 3-2. Vehicle Locations

	Ford Taurus		Chevrolet Lumina			Dodge Spirit		Chevrolet 2500		Dodge Ram Van		Ford Econoline		TOTAL VEHICLES			
LOCATION	M85	Gaso-line	M85	E85	Gaso-line	M85	Gaso-line	CNG	Gaso-line	CNG	Gaso-line	M85	Gaso-line	M85	E85	CNG	Gaso-line
Washington, D.C.	15	15	24	40	22	50	26	50	5	25	19	9	14	98	40	75	101
Denver, CO	13	13	13	0	13	50	26	32	26	20	20	10	10	86	0	52	108
Houston, TX	0	0	0	0	0	30	5	30	5	3	0	0	0	30	0	33	10
Detroit, MI	15	2	5	0	2	52	26	0	0	0	0	0	0	72	0	0	30
New York / NJ	0	0	0	0	0	50	5	46	26	5	5	0	0	50	0	51	36
El Paso, TX	0	0	0	0	0	0	0	48	2*	0	0	0	0	0	0	48	2*
Bakersfield, CA	0	0	0	0	0	0	0	0	0	20	5*	0	0	0	0	20	5*
Los Angeles, CA	5	2	6	0	2	0	0	0	0	0	0	0	0	11	0	0	4
San Diego, CA	5	2	6	0	2	0	0	0	0	0	0	0	0	11	0	0	4
Argonne, IL	1	0	3	5	2	14	0	4	0	5	0	0	0	18	5	9	2
TOTALS	54	34	57	45	43	246	88	210	64	78	49	19	24	376	45	288	302

* Vehicles added in fiscal year 1994

geographic locations. The expansion of the Detroit region and addition of the New York region permit the evaluation of cold-weather performance of M85, E85, and compressed natural gas, whereas the addition of the Houston region provides a warm-weather environment for similar evaluations. The Denver region will provide a means to evaluate alternative fuel vehicles performance at high altitudes. The Denver region has just started operations and there have not been enough data generated to make vehicle performance comparisons based on altitude.

3.3 Vehicle Usage Patterns

Driving patterns and daily usage will affect vehicle performance parameters such as fuel economy. When making comparisons between regions, it is necessary to consider the differences in both climate and usage patterns. Of the five major regions, fleet managers at both Washington, D.C., and Houston reported that their operations experienced little to no rural driving. For the Detroit, Denver, and New York regions, fleet managers classified about 10 percent of their operation as rural. The upstate New York vehicles account for all of the rural driving in that region. It is also interesting to note that the Houston region fleet managers reported the largest urban driving segment at 86 percent, with the Washington, D.C., fleet managers reporting the second largest at 50 percent. Because these demographics are based on fleet manager judgments of what constitutes an "urban" versus "suburban" location, some biases in the data may be present.

The regions with smaller fleet sizes allow for more-controlled usage. For example, the Bakersfield, California, location has compressed natural gas vans which cover 50 to 90 miles daily, with minimum of stop-and-go traffic. This can be compared and contrasted with the El Paso, Texas, location, which operates compressed natural gas pickups. These vehicles average only 10 to 40 miles per day and often involve extended periods of idling and low-speed travel.

3.4 Technical Characteristics

Currently, six vehicle models are represented in the program, the 1991/1992/1993 Chevrolet Lumina, 1992/1993 Chevrolet C2500 pickup truck, 1991/1992/1993 Ford Taurus, 1993 Dodge Spirit, 1993 Ford Econoline van, and 1992/1993 Dodge B-250/350 van. Although these vehicles outwardly appear no different from conventional gasoline vehicles, they incorporate various fuel-system and engine modifications in order to operate on methanol/gasoline mixtures, ethanol/gasoline mixtures, and compressed natural gas fuel. Appendix A details the specific modifications which were made to each model vehicle.

3.5 Infrastructure Support

3.5.1 Fuel Suppliers

Currently, M85 is being supplied by fuel suppliers at more than 78 public refueling facilities throughout the United States. The major participating oil companies are ARCO, Chevron, Conoco, Methanex, Exxon, Mobil Oil Company, Shell Oil Company, and Sun Oil Company. In Washington, D.C., there is one public M85 refueling station located at 50 M

Street, SE, which is owned and operated by Sun Oil Company. All regions in the tests have at least one M85 refueling location with the exception of the New York region. However, there are plans to open two M85 facilities in that region in the spring of 1994.

Compressed natural gas is being supplied by various natural gas utilities throughout the United States. Currently, there are more than 730 compressed natural gas refueling facilities in the United States. About 75 percent of these are owned by natural gas utilities, while about 10 percent are publicly owned. In Washington, D.C., there is one public compressed natural gas refueling station located at 823 Pennsylvania Avenue, SE, which is owned and operated by AMOCO. At this time, all regions have access to compressed natural gas facilities except for the upstate New York area, which has plans to install a refueling site scheduled to open in the spring of 1994.

Currently, E85 is being supplied by fuel suppliers at more than 30 public refueling facilities. In Washington, D.C., there is one public E85 refueling station located at 1248 Pennsylvania Avenue, S.E., which is owned and operated by Sun Oil Company. All of the regions which have been assigned E85 vehicles have at least one E85 refueling facility.

3.5.2 Authorized Repair Facilities

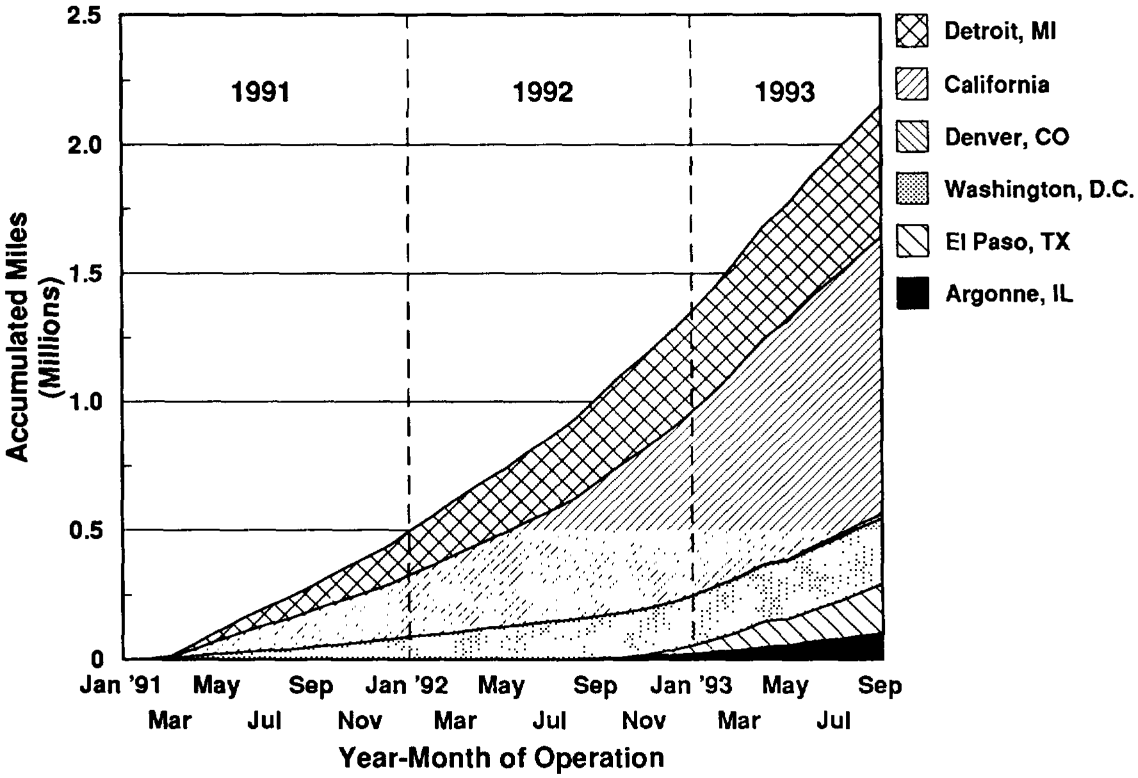
With the vast expansion of alternative fuel vehicles in the Federal fleet, a greater demand has been placed upon the automotive manufacturers to provide the service and spare parts infrastructure support. For the most part, the supply of parts and trained mechanics has been adequate because of the careful placement of alternative fuel vehicles. During Phase I, vehicles were placed in locations close to specified service centers. By starting the project on a small scale and then ramping up the number of vehicles slowly, the automotive manufacturers have had valuable time to develop repair procedures and to set up mechanic training. Now that these training materials and the parts supply network are in place, Phase II regions have been able to start operations without difficulty.

3.6 Vehicle Performance/Operations

3.6.1 Mileage Accumulation

Through fiscal year 1993, 2,154,838 miles have been accumulated for Phase I and Phase II vehicles. Figure 3-2 illustrates the mileage accumulated for each project. In this figure, the Los Angeles, Bakersfield, and San Diego projects were combined and shown as California. It also should be noted that many of the Phase II vehicles and regions were starting operations but had not yet provided data. The dramatic increase in project size will become apparent with large mileage accumulations projected for fiscal year 1994. Figure 3-3 illustrates the mileage accumulation by the vehicle fuel type. Although the largest amount of miles (1,262,386) was accrued by the M85 vehicles, there were many in this group which did not use M85 fuel. Compressed natural gas vehicles accumulated 515,874 miles. Because operations for these vehicles started in fiscal year 1993, the mileage accumulations for these vehicles are modest. Accumulations for these vehicles are projected to increase dramatically during fiscal year 1994. The E85 vehicles (which operated only in the Argonne, Illinois, and Washington, D.C., areas) accumulated 43,342 miles.

Figure 3-2. Accumulated Miles by Fleet Location



3.6.2 Fuel Usage

3.6.2.1 Total Fuel Consumption

Figure 3-4 presents the total fuel consumption of Phase I and Phase II vehicles for the 1993 fiscal year. By the end of the year, more than 41,000 gasoline gallon equivalent of natural gas, about 20,000 gallons of M85, nearly 3,000 gallons of E85, and more than 12,000 gallons of gasoline were consumed.

3.6.2.2 Alcohol Fuel Utilization

To further understand the amount and apportionment of M85 to gasoline and E85 to gasoline fuel used and its relative impact on in-use vehicle operation, a refueling index was computed. The refueling index is the ratio of the amount of M85 or E85 fuel used in gallons compared with the total amount of fuel (M85 or E85 and gasoline fuel) used in gallons, for each of the four locations. As shown in Figure 3-5 for Phase I projects, the refueling index ranges from about 73 percent for San Diego, California, to 94.7 percent for Detroit, Michigan. This indicates that, of the total amount of fuel used for operating the alternative fuel vehicles, the majority of fuel used was M85 or E85 for these locations. These M85 uses are high because the vehicle locations were centralized around available M85 refueling

Figure 3-3. Accumulated Miles by Vehicle Fuel Type

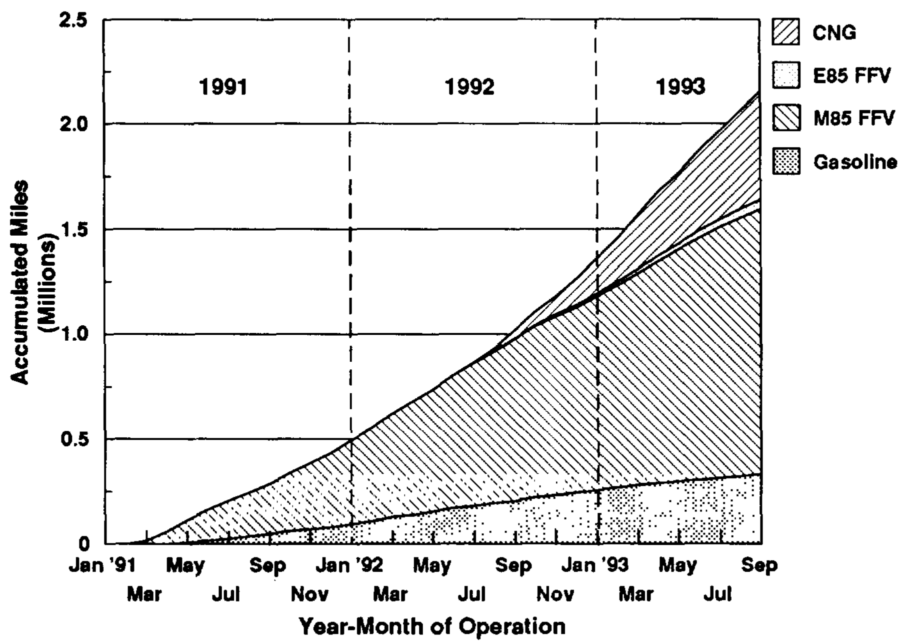


Figure 3-4. Cumulative Fuel Used - All Sites from October 1992 to September 1993

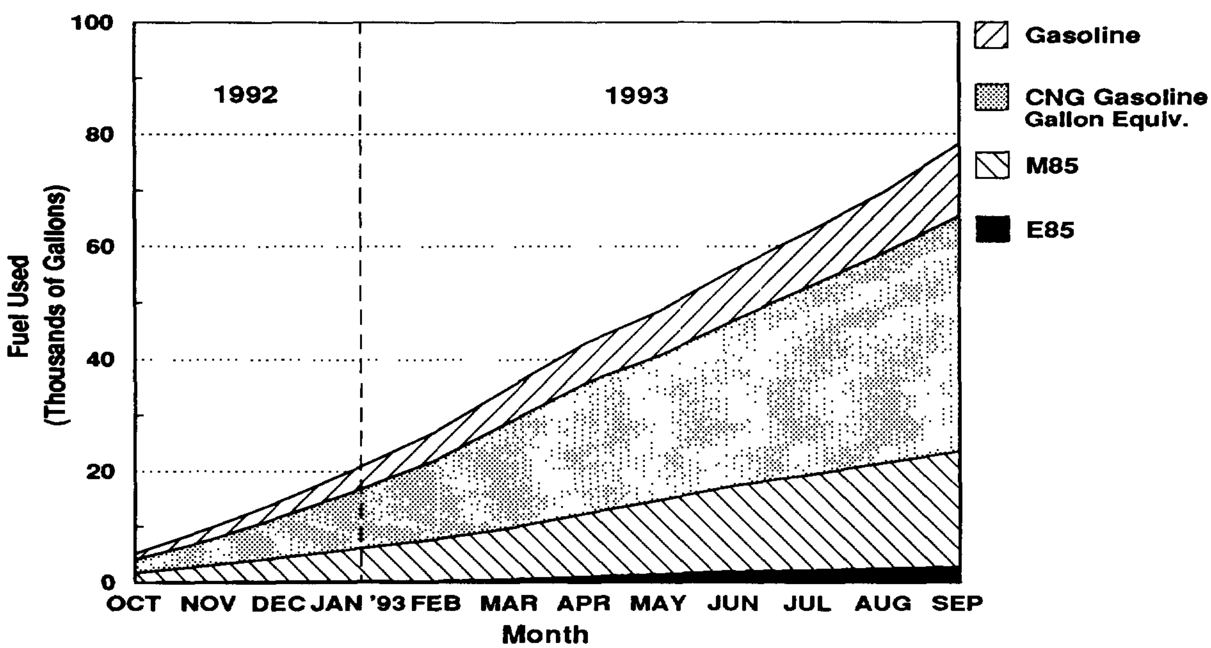
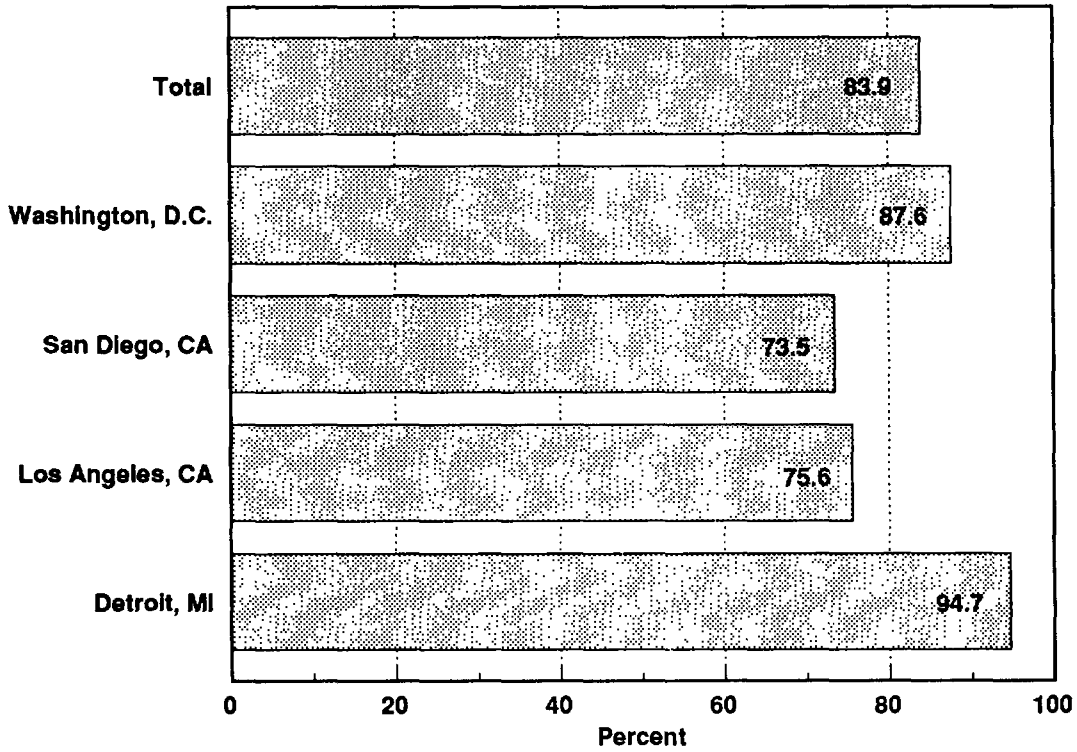


Figure 3-5. Phase I Alcohol Fuel Utilization



Source: National Renewable Energy Laboratory

facilities and DOE and the General Services Administration have placed great emphasis on the need for sites to operate on alternative fuels. Flexible-fuel vehicles or dual-fuel vehicles which are not in a demonstration project might not be operated so frequently on alternative fuels. It is projected that the alcohol fuel utilization rate will fall somewhat during fiscal year 1994 because the Phase II projects are much larger and more widely dispersed.

3.6.3 Challenges of Operation

As with any large expansion of a project, there have been a number of startup problems. Often these problems simply involve inadequate coordination or poor timing. The most frequent problems encountered on startup involve the lack of alternative fuel refueling facilities. For the flexible-fuel vehicles (M85/E85), this is not a significant problem because these vehicles can operate on gasoline until alternative fuel refueling sites become available. However, those compressed natural gas vehicles that are dedicated fuel vehicles must have adequate local refueling facilities in order to function. An example of this involves the West Point, New York, location which has twelve C2500 pickups and cannot start operations until the planned refueling facility is completed. Many compressed natural gas refueling locations do not have adequate fuel-metering devices to enable the operator to record how much fuel was put into the vehicle, hampering the collection of refueling data at these locations.

For both the compressed natural gas vehicles and alcohol-fueled vehicles, several driveability problems were encountered. The Chevrolet compressed natural gas C2500 pickups experienced numerous problems such as stalling, surging, and failure to start. These problems have been traced to debris in the fuel lines left over from various manufacturing processes. This debris has resulted in the frequent replacement of injectors and fuel filters. The compressed natural gas Dodge vans also experienced numerous driveability problems, which were solved by replacing the engine control computer with an updated version.

With compressed natural gas vehicles, there are two primary refueling connectors which are not compatible. In addition, the use of adapters is not very easy. As a result, operators may encounter difficulty in finding refueling stations with the correct connector. A new standardized connection identified as NGV1 is expected to be installed on compressed natural gas vehicles and refueling stations in the near future, eliminating much of this problem.

The M85 Dodge Spirits that are part of the Phase II project arrived with leaking alcohol-percentage sensors, which needed to be replaced and delayed the availability of these vehicles for use.

Initial driveability problems that occurred with the M85 Ford Taurus were largely attributed to performance degradation of various unique components of the vehicle, such as the EEC-IV engine microprocessor, fuel-sending unit, and fuel-pressure regulator. Upgrade kits were subsequently delivered to the participating authorized Ford service centers, and the upgraded hardware was installed on the vehicles exhibiting driveability problems.

The driveability problems that occurred with the M85 Chevrolet Lumina were largely attributed to performance degradation of the unique fuel injector and fuel pump speed-controller components. However, an updated dealer service bulletin was issued in November 1991 to the participating authorized General Motors service centers, outlining the driveability problems, possible causes, and correct repair procedures to follow (install new service calibration programmable read-only memory (prom) computer chip and fuel-pump speed controller).

Some of the long-term problems encountered have involved specific vehicle limitations. Several characteristics of the alternative fuel vehicles have limited their popularity. The most significant of these involve a reduction in driving range. For both alcohol and compressed natural gas fuels, the amount of energy contained in a specified volume is less than that of gasoline. Thus, for the same size fuel tank, the vehicle's range is reduced. In some of the M85 vehicles this has been addressed by installing slightly larger fuel tanks. The compressed natural gas vehicles have the largest number of complaints concerning travel range. This is due to the fact that dedicated compressed natural gas vehicles can use only compressed natural gas, and drivers must plan their use very carefully to ensure that adequate refueling facilities are available. In addition, the compressed natural gas fuel tanks, which are filled with up to 3,600-pounds-per-square-inch pressure, are bulky and not easy to package. The compressed natural gas C2500 pickup truck has an extra fuel tank installed in the bed to increase its range. Unfortunately, this limits the ability to haul large items. Compressed natural gas vehicles also typically take a long time to refuel. Many vehicle locations have onsite "slow fill" capabilities and thus take an extended period of time to refuel the vehicle. For many operations, "slow-fill" refueling is conducted overnight and does not affect the efficiency of the overall vehicle operation. Public compressed natural gas locations are usually state-of-the-art "fast fill" facilities. Although these facilities are becoming more common, it will take time before they replace enough of the "slow fill" facilities to change the users' perceptions that compressed natural gas vehicles are slow to refuel.

3.7 Efficiency of Performance/Cost

Collection of data concerning fuel usage is an integral part of the Light-Duty Alternative Motor Fuels Program. For Phase I, drivers of project vehicles are required to record odometer readings at the beginning and end of each day, and the amount of fuel added during the week. This information is recorded by each driver in a weekly log sheet. For Phase II, a data input form is completed by the driver at refueling and mailed to the data collection contractor. The data are then entered and pre-screened before being submitted to the Alternative Fuels Data Center. These records are used to calculate the on-road fuel economy.

3.7.1 Fuel-Economy Analysis Methodology

From October 1992 through September 1993, there were over 9,500 recordings of refueling events. Because these data are used for subsequent fuel-economy calculations, it is necessary to assure that the data are as error-free as possible. First, the data that were obviously incorrect were eliminated. Most appeared to be due to transcription errors that resulted in unrealistically high or low fuel-economy values. Once the erroneous data were eliminated, the next step was to eliminate fuel-type changes (i.e., refueling an M85 alternative fuel vehicle on gasoline, then next on M85; or similarly, refueling a gasoline control alternative fuel vehicle on M85, then next on gasoline). For example, when an M85 alternative fuel vehicle was refueled once with gasoline then next with M85, the gasoline refueling and the next two M85 refueling entries were eliminated. By eliminating these data, the calculated M85 and gasoline alternative fuel vehicle fuel-economies reflected operation almost exclusively on M85 and gasoline fuel, respectively. Of the more than 9,500 refueling data points collected from October 1992 through September 1993, about 15 percent were removed through the elimination of erroneous and mixed fuel-type data.

On-road fuel economies for nine of the ten sites are summarized in Table 3-3 on the basis of cumulative fuel economy and gasoline energy-equivalent fuel economy. The cumulative fuel economy includes a running total of all miles traveled and fuel consumed. Gasoline gallon equivalent miles per gallon is the M85 alternative fuel vehicle fuel economy adjusted for the difference in fuel energy content between gasoline and M85. It is often desirable to compare gasoline fuel economy to M85 fuel economy on a gasoline gallon equivalent basis to show relative fuel-energy economy.

Examination of the on-road fuel economies, when adjusted for fuel energy, reveals that for most of the sites, the M85 alternative fuel vehicles have slightly higher fuel economy than the conventional gasoline vehicles. The exceptions to this are the Luminas in Washington,

Table 3-3. On-Road Fuel Economy Summary

CHEVROLET LUMINA

Federal Fleet Sites	Vehicle Type	Fuel	Cumulative Fuel Economy: miles/gallon (range)	Cumulative Fuel Economy: miles/gallon — gasoline/gallon equivalent[a]	No. of Vehicles That Contributed to this Sample
Washington, D.C.	M85	M85	11.9 (5.1 - 43.3)	21.0	7
	M85	Gasoline	16.9 (14.3 - 18.6)	--	1
	Gasoline	Gasoline	23.2 (16.6 - 35.5)		2
	E85	E85	10.5 (5.1 - 43.1)	14.9	8
	E85	Gasoline	--[b]	--	--
	Gasoline	Gasoline	23.2 (16.6 - 35.5)		2
Argonne, IL	E85	E85	16.8 (8.5 - 28.3)	23.7	5
	E85	Gasoline	25.4 (13.5 - 43.3)	--	4
	Gasoline	Gasoline	--[b]		--
Detroit, MI	M85	M85	15.4 (9.7 - 43.7)	27.1	3
	M85	Gasoline	27.6 (18.3 - 39.6)	--	1
	Gasoline	Gasoline	25.4 (8.6 - 43.0)		2
Los Angeles, CA	M85	M85	17.1 (7.3 - 42.6)	30.1	5
	M85	Gasoline	19.3 (12.2 - 36.5)	--	1
	Gasoline	Gasoline	25.6 (7.5 - 39.3)		2
San Diego, CA	M85	M85	18.2 (9.1 - 42.9)	32.2	4
	M85	Gasoline	22.1 (21.5 - 25.7)	--	1
	Gasoline	Gasoline	21.6 (10.4 - 36.4)		2

FORD TAURUS

Federal Fleet Sites	Vehicle Type	Fuel	Cumulative Fuel Economy: miles/gallon (range)	Cumulative Fuel Economy: miles/gallon — gasoline/gallon equivalent[a]	No. of Vehicles That Contributed to this Sample
Washington, D.C.	M85	M85	13.1 (5.0 - 38.2)	23.0	9
	M85	Gasoline	--[b]	--	--
	Gasoline	Gasoline	18.6 (14.3 - 28.1) [b,c]		1
Detroit, MI	M85	M85	16.3 (9.4 - 44.4)	28.7	11
	M85	Gasoline	24.6[b]	--	1
	Gasoline	Gasoline	23.6 (10.7 - 44.9)		2
Los Angeles, CA	M85	M85	13.8 (9.2 - 44.3)	24.4	2
	M85	Gasoline	25.1 (13.0 - 44.6)	--	1
	Gasoline	Gasoline	26.5 (6.7 - 43.4)		2
San Diego, CA	M85	M85	16.9 (8.5 - 33.5)	29.9	3
	M85	Gasoline	24.2 (13.1 - 40.5)	--	1
	Gasoline	Gasoline	21.4 (13.3 - 31.5)		1

a Gasoline gallon equivalent miles per gallon is the M85/E85 fuel economy adjusted for the difference in fuel-energy content between gasoline and M85/E85 (e.g., M85 has 56 percent of the energy of unleaded gasoline, and E85 has 71 percent of the energy of unleaded gasoline).

b Based on limited information or not yet available.

c Calculation supplemented with non-fiscal-year 1993 fuel-economy data.

Table 3-3. On-Road Fuel Economy Summary (continued)

DODGE SPIRIT

Federal Fleet Sites	Vehicle Type	Fuel	Cumulative Fuel Economy		No. of Vehicles That Contributed to this Sample
			miles/gallon (range)	miles/gallon — gasoline/gallon equivalent[a]	
Argonne, IL	M85	M85	11.0 (6.8 - 22.3)	19.5	14
Denver, CO	M85	M85	10.1[b]	17.8	3
Washington, D.C.	Gasoline	Gasoline	24.6 (15.9 - 44.5)		4

DODGE B250/B350 RAM VAN

Federal Fleet Sites	Vehicle Type	Fuel	Cumulative Fuel Economy		No. of Vehicles That Contributed to this Sample
			miles/gallon	miles/gallon — gasoline/gallon equivalent[c] (range)	
Denver, CO	CNG Gasoline	CNG Gasoline	15.0[b]	12.7 (1.5 - 26.9)	13 1
Houston, TX	CNG	CNG		9.1 (3.3 - 22.6)	3
Bakersfield, CA	CNG	CNG		11.8 (1.0 - 29.7)	20

CHEVROLET C2500 PICKUP

Federal Fleet Sites	Vehicle Type	Fuel	Cumulative Fuel Economy	No. of Vehicles That Contributed to this Sample
			miles/gallon — gasoline/gallon equivalent[c] (range)	
Denver, CO	CNG	CNG	9.0 (1.3 - 22.2)	28
Houston, TX	CNG	CNG	11.2 (1.2 - 29.3)	24
El Paso, TX	CNG	CNG	12.5 (1.2 - 29.9)	48

a Gasoline gallon equivalent miles per gallon is the M85 fuel economy adjusted for the difference in fuel-energy content between gasoline and M85 (e.g, M85 has 56 percent of the energy of unleaded gasoline).

b Based on limited information or not yet available.

c Gasoline gallon miles per gallon is the CNG fuel economy adjusted for the difference in fuel-energy content between gasoline and CNG.

D.C., and the Tauruses in Los Angeles. Overall, the on-road fuel economies of the compressed natural gas alternative fuel vehicles, when adjusted for fuel energy, are lower than the conventional gasoline vehicles.

3.7.2 Laboratory Fuel Economy

Fuel economies of selected vehicles from the Washington, D.C., and Detroit areas were determined based on laboratory testing conducted during fiscal years 1992 and 1993. The vehicles tested included M85 alternative fuel vehicles, gasoline alternative fuel vehicles, and conventional gasoline vehicles. The vehicles were tested at the Environmental Research and Development Corporation in Gaithersburg, Maryland; the U.S. Environmental Protection Agency National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan; and the U.S. Environmental Protection Agency's Research Triangle Park, North Carolina facility (operated by Mantech, Inc). The fuel economies of the M85 alternative fuel vehicles were measured on M85 and Indolene to determine the difference in vehicle fuel economy on both fuels. Indolene is the trade name for a gasoline with highly controlled properties that is used for vehicle emission testing.

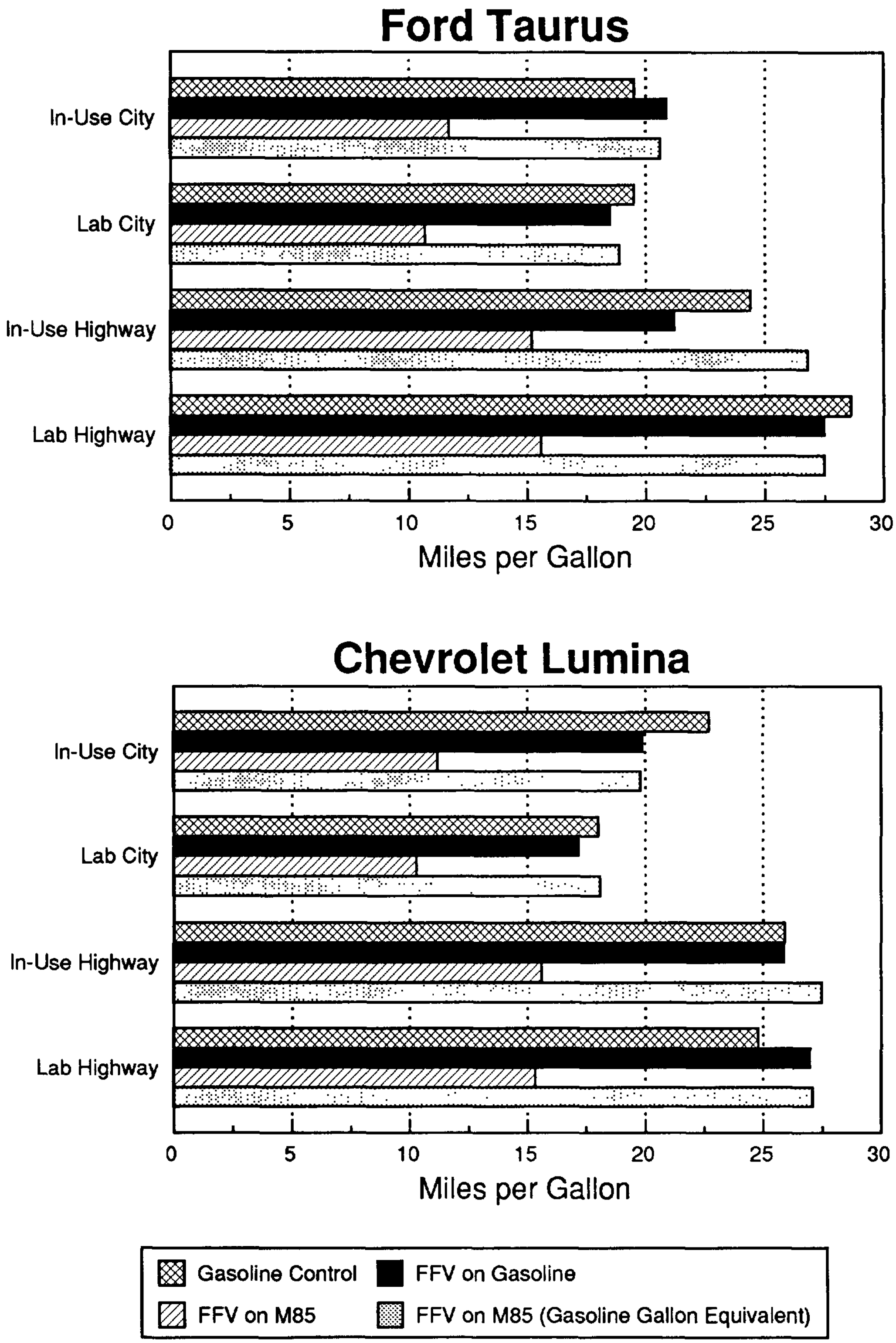
The test procedure used in determining fuel economy for the certification of new vehicles by the Federal Government is the Federal Test Procedure, which is also used to measure emissions. Vehicle fuel economy during the Federal Test Procedure was determined by measuring the mass of the carbon in the vehicle emissions. A carbon-balance method is used to calculate the amount of fuel consumed by the vehicle over the prescribed "city" or "highway" driving schedules. The 1975 Federal Test Procedure Schedule is used to calculate official "city" fuel economy values. The Highway Fuel Economy Test Schedule is used to obtain the official "highway" fuel economy values. These fuel economy tests were performed to determine fuel economy differences under controlled laboratory conditions, using the same driving cycle, to rule out influences of weather, driving habits, and other factors.

Figure 3-6 and Table 3-4 summarize the comparison between in-use fuel economy and the laboratory fuel economy for both the Taurus and Lumina. The in-use highway calculations were based on vehicles that reported mileage greater than 50 miles per day. The city calculations were based on vehicles that reported mileage less than 50 miles per day. Comparison of the fuel economy reveals that for both the in-use and laboratory cases, the fuel economy for M85 alternative fuel vehicles fueled on M85, when adjusted for fuel energy, was similar to the fuel economy of the M85 alternative fuel vehicles fueled with gasoline.

3.7.3 Operating and Life-cycle Costs

Operating cost data are being collected from the General Services Administration and are currently being analyzed. Life-cycle cost analysis will be conducted following the removal and resale of the vehicles from the Federal fleet and will include factors such as vehicle purchase price, operating costs (over the mission profile of the vehicle), operation efficiencies (e.g. lost productivity due to increased time for CNG refueling or extended service periods), and vehicle resale value.. These detailed cost analyses will be presented in future reports.

Figure 3-6. Comparison Between In-Use and Laboratory Fuel Economy for the Ford Taurus and Chevrolet Lumina



Note: City Fuel-Economy Data were reduced 10% and Highway Fuel-Economy Data were reduced 22% for comparison with in-use fuel economy data.

Table 3-4. Fuel Economy In-Use Versus Laboratory

			In-Use		Lab	
Vehicle	Type	Fuel	City[a] miles/gallon (gasoline gallon equivalent)	Highway[b] miles/gallon (gasoline gallon equivalent)	City[c] miles/gallon (gasoline gallon equivalent)	Highway[d] miles/gallon (gasoline gallon equivalent)
Lumina	VFV	M85	11.2 (19.8)	15.6 (27.5)	10.3 (18.1)	15.35 (27.1)
Lumina	VFV	Gasoline	19.9	25.9	17.2	27.0
Lumina	Conv.	Gasoline	22.7	25.9	18.0	24.8
Taurus	FFV	M85	11.7 (20.6)	15.2 (26.8)	10.7 (18.9)	15.6 (27.5)
Taurus	FFV	Gasoline	20.9	21.2	18.5	27.5
Taurus	Conv.	Gasoline	19.5	24.4	19.5	28.6

Source: National Renewable Energy Laboratory

[a] In-use fuel economy based on average daily mileage less than 50 miles.
[b] In-use fuel economy based on average daily mileage greater than 100 miles.
[c] City fuel-economy data were reduced 10 percent per standard EPA practice for comparison with in-use data.
[d] Highway fuel-economy data were reduced 22 percent per standard EPA practice for comparison with in-use data.

3.8 Laboratory Emissions

Collection of emissions data is a very important part of the Light-Duty Alternative Motor Fuels Program. Over the past fiscal year, an expanded emissions data base has been developed from the Phase I project. Since 1991, 150 emissions tests have been performed in accordance with test procedures specified by the Environmental Protection Agency. Data from 18 Phase I vehicles in the Detroit and Washington, D.C., regions were used in developing the information for this report. Vehicles represented include Taurus M85 flexible-fuel and Lumina M85 variable-fuel vehicles operated on gasoline and M85 and standard control vehicles operated on gasoline. Substantive emission testing of Phase II compressed natural gas vehicles started after fiscal year 1993, therefore, analysis based on these data will be presented in next year's report. Three emissions test laboratories, the Environmental Protection Agency's Ann Arbor, Michigan, facility, the Environmental Protection Agency's Research Triangle Park, North Carolina facility (operated by Mantech, Inc.), and the Environmental Research & Development Corporation facility in Gaithersburg, Maryland, conducted the tests. Although some additional fuel formulations were tested on a very limited number of vehicles, the focus of this report is on trends associated with comparisons of emissions between gasoline and M85 fuels. In several tests, unburned hydrocarbon emissions were further examined to more fully characterize the nature of specific compounds (a laboratory analysis process known as speciation). These data are still being analyzed.

The test procedures used for performing emission tests were described briefly in the previous report to Congress and will not be discussed further here. The procedures, equipment, test conditions, process, and analysis requirements are specified by the Environmental Protection Agency in the Code of Federal Regulations Title 40: Part 86

Subpart B - Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks; Test Procedures. Test vehicles were tested at various mileage increments as shown in the graphs and tables which accompany this report section.

In accordance with the Federal Test Procedure, the exhaust of each test vehicle was sampled and analyzed for three major emission constituents: carbon monoxide (CO), total unburned hydrocarbons (THC), and oxides of nitrogen (NO_x). For methanol-containing fuels, the term organic material hydrocarbon equivalent (OMHCE) is used rather than hydrocarbons. The organic material hydrocarbon equivalent is determined by the summation of the mass of residual hydrocarbons and adjusted to the values of methanol and formaldehyde, comparable to hydrocarbons for gasoline engines.

The following series of graphs and tables illustrate trends, with mileage, for the various vehicles which were tested. Note from the graphs that emissions data were obtained at various mileage points which are not always consistent across the group of vehicles tested. This resulted from several factors, but is primarily related to the combination of vehicle availability and test laboratory availability. With the limited number of vehicles being tested, precise, statistically significant statements are difficult to make at this time. As discussed in the report section on Future Activities, the emissions test component of the Light-Duty Alternative Motor Fuels Program has been expanded significantly to improve the base of emissions data and thus enhance the significance of results. In compiling the data for this report, composite data on vehicles of like type, tested on like fuels, at approximately like mileage points were grouped for analysis purposes.

With the very limited set of emissions data (at early vehicle mileage accumulation points) that were available for previous annual reports, it was convenient to express results in simple bar chart form. Because emissions data are now available over extended vehicle mileage intervals, trends with mileage can be illustrated. The traditional method for illustrating emission trends with mileage is to denote the emission values for the mileage points at which the vehicles were tested, then "connect the dots" to illustrate the overall trend. It is important to note that interpolation between each test point is not generally advised, because different results might have been obtained if the vehicle were to have been tested at an intermediate mileage point.

The data illustrated in the following graphs represent the average of the emissions for the subgroup of like vehicle/fuel combinations. For the sake of clarity, the highest and lowest emissions data for each point (illustrating the range of emission variability) are not shown because such information would have no effect on the overall trends illustration. A discussion of emission variability (and several explicit examples) are discussed later in this report section. The results allow the inference of comparative trends. This presentation technique permits relative assessments to be made without the need for being overly reliant on the absolute values of specific emission results, because there are many factors that contribute to the variability of emission test results.

Before beginning the discussion of emission trend results, a few additional points are worth mentioning. The current emission standards that the automotive manufacturers were required to meet are as follows: 0.41 grams per mile total hydrocarbons, 3.4 grams per mile carbon monoxide, and 1.0 grams per mile oxides of nitrogen. Well in advance of new model-year production, each automotive manufacturer develops a fleet of prototype vehicles for emission certification. These vehicles are intended to be representative of vehicles for the new model year. A very rigorous mileage-accumulation and emission-testing program is carried out to demonstrate compliance of the prototype vehicle fleet with the applicable model-year emission standards. Relative to typical manufacturing volumes for production vehicles (which may number in the hundreds of thousands for some models), the number of prototype vehicles used for a manufacturer's emission certification program is very small (often, a few hundred or less). As such, the emissions characteristics of high-volume production vehicles do not always match the characteristics of the prototypes that were used for certification. Evidence of such differences appear to be reflected in some of the vehicles selected for emission testing in the Phase I project. The Phase I Ford Taurus flexible-fuel vehicles supplied for the project are not emissions certified and are operating as "experimental vehicles." As such, their emissions might not be expected to be comparable to those of production-level gasoline vehicles.

Another point of importance has to do with the overall variability associated with emission test data. Contributions to such variability come from vehicle differences, test driver differences, tolerance stack-up on test equipment and emission analyzers, differences among test laboratories, variations in vehicle-preparation procedures, and variations in specific test conditions (especially in humidity and barometric pressure). Although the reasons cited above do contribute to variability, the bulk of the variability cannot be accounted for by variations in test conditions. In general, overall variability in reported test data across all cars, laboratories, etc., of 20 percent or less is considered excellent. Many of the collective test points used for the analysis contained in this report were well within that range. Substantially larger "scatter" occurred in a significant number of carbon monoxide data points, however, making it difficult to ascribe much precision to those data. An example is shown later in this section for illustration purposes.

Figures 3-7, 3-8, and 3-9 illustrate composite data for total hydrocarbon (and organic material hydrocarbon equivalent, for the methanol fuels), carbon monoxide and oxides of nitrogen emissions for M85 variable-fuel vehicle Luminas tested at about 12,000 and 24,000 miles on Indolene gasoline, M85, and M50 (a mixture of 50 percent methanol and 50 percent unleaded gasoline). Emission testing using M50 provides valuable data about the vehicle emission performance for a mid-range methanol/gasoline concentration which is commonly encountered during in-use operation whenever the vehicle switches fuel type). Note the increasing trend in total hydrocarbon emissions for all three fuels. Note also the increasing trend in carbon monoxide emissions for all three fuels. Oxides of nitrogen emissions exhibit a mixed trend, with the M85 fuel showing a slight increase with mileage. Table 3-5 contains a comparison of the relative change in emissions, with mileage, for each test fuel.

Figure 3-10 shows composite data for the M85 variable-fuel vehicle Luminas that have been tested at various mileage points with Indolene and M85. Note the "U-shaped" trend in carbon monoxide emissions for both fuels and the early modest growth, then essentially flat characteristics, of the hydrocarbon and oxides of nitrogen emissions for both fuels. Prior to about 4,000 vehicle miles, engine and vehicle break-in is usually still occurring. Thus, limited significance should be attached to any emission data prior to that point. A similar

Figure 3-7. THC and OMHCE Emissions for M85 VFV Luminas Tested with Indolene, M85, and M50

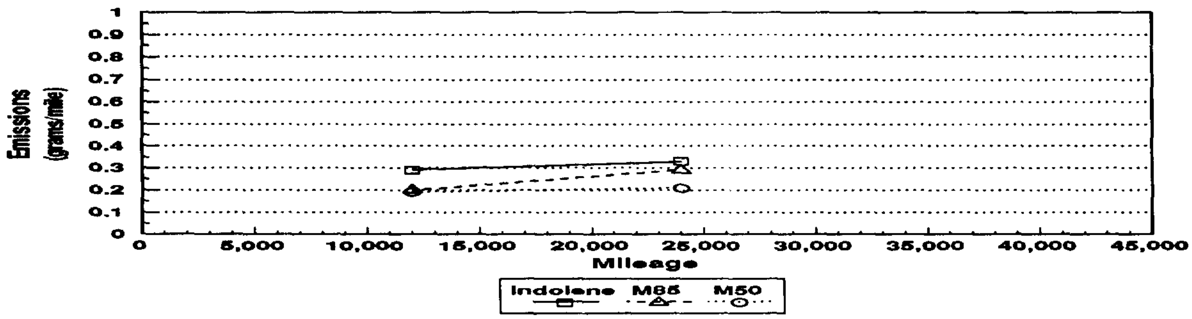


Figure 3-8. CO Emissions for M85 VFV Luminas Tested with Indolene, M85, and M50

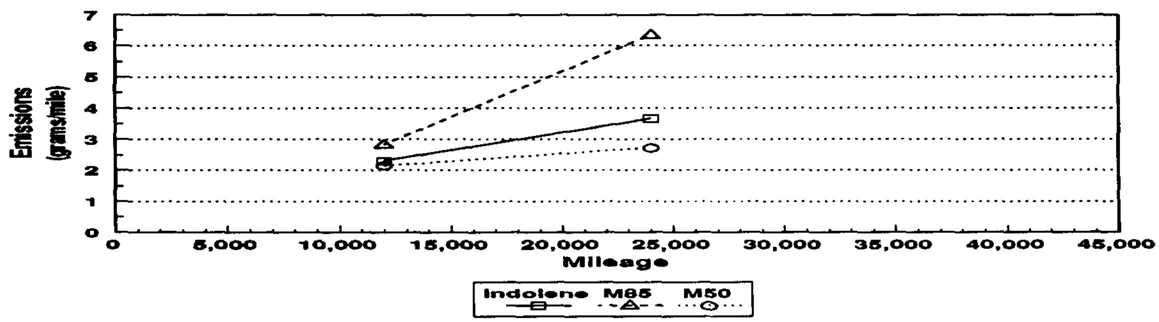


Figure 3-9. NO_x Emissions for M85 VFV Luminas Tested with Indolene, M85, and M50

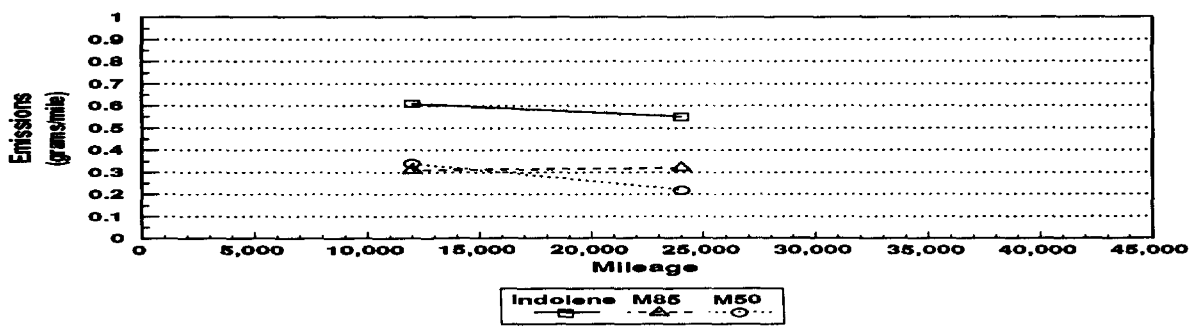


Table 3-5. Comparison of Indolene, M85, and M50 Test Fuels in M85 Luminas

Test Fuel	Percent Change in Emissions from 12,000 miles to 24,000 miles			
	THC	OMHCE	CO	NO_x
Indolene	+14	N/A	+46	-10
M85	N/A	+33	+124	+3
M50	N/A	+17	+26	-35

plot of data for the Ford flexible-fuel vehicle Tauruses is shown in Figure 3-11. Note that test points beyond about 14,000 miles have not been obtained yet for these vehicles, and future trends might be different from those shown.

In Figure 3-12, comparisons are shown for M85 variable-fuel vehicle Luminas (which, in general, were operated mostly with M85 during mileage accumulation) and M85 variable-fuel vehicle control Luminas (which were operated on gasoline-only during mileage accumulation) tested on Indolene fuel. Except for the somewhat higher level of oxides of nitrogen for the M85 Luminas, the mileage trends and overall emission levels appear to be quite similar.

M85 variable-fuel vehicle Luminas tested with M85 fuel and gasoline control Luminas tested on Indolene are compared in Figure 3-13. This comparison illustrates emissions from vehicles as they were intended to be operated on specific fuels, i.e., M85 variable-fuel vehicle Luminas on M85 and standard-production Luminas on gasoline. The gasoline control vehicles have been emission-tested through 42,000 miles, whereas the M85 Luminas have only been tested up to about 24,000 miles. Although the trends are similar through 24,000 miles, further testing of the M85 Luminas will determine if their trends continue to follow those of the gasoline control Luminas. Note the distinct drop in composite carbon monoxide emissions for the gasoline control vehicles between 14,000 miles and 16,000 miles. There was nothing unusual in the vehicle operating data between those two points to provide an explanation for these emission test results. Figure 3-14 is a similar set of comparisons for the M85 flexible-fuel vehicle Tauruses tested on M85 and the gasoline control Tauruses tested on Indolene. As with the M85 Luminas, much more mileage accumulation and emission testing is required to determine if the M85 Tauruses will ultimately follow the gasoline control-vehicle trend. The emissions of the gasoline control Tauruses have maintained a constant level after 25,000 miles.

Figure 3-15 illustrates a comparison between M85 flexible-fuel vehicle control Tauruses (operated exclusively on gasoline during mileage accumulation) and gasoline control Tauruses tested on Indolene. This figure provides an indication of emission behavior when

Figure 3-10. Emissions Comparisons for M85 VFV Luminas Tested with Indolene and M85

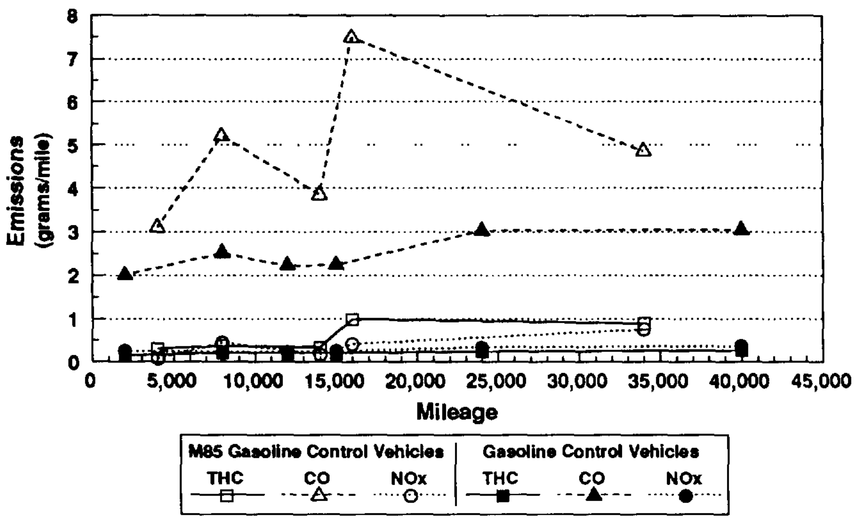


Figure 3-11. Emissions Comparisons for M85 FFV Tauruses Tested with Indolene and M85

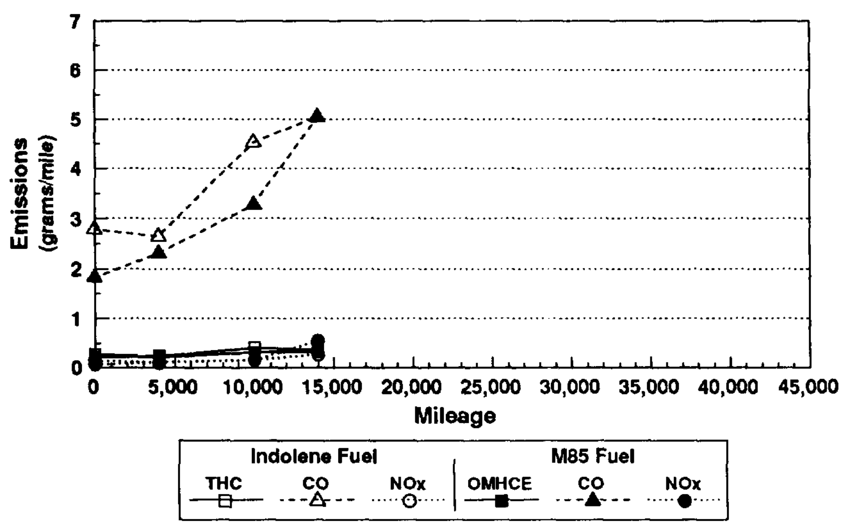


Figure 3-12. Emissions Comparisons for M85 VFV Luminas and M85 VFV Lumina Control Vehicles Tested with Indolene

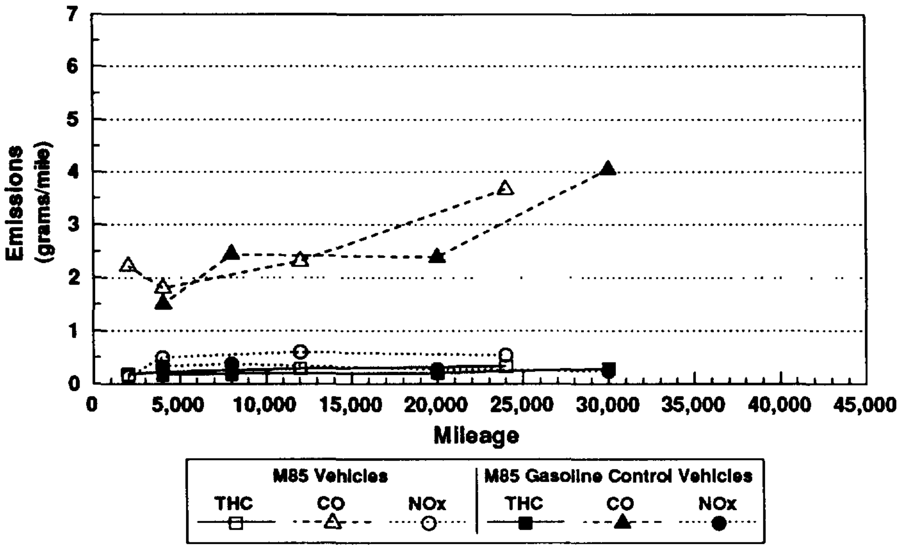


Figure 3-13. Emissions Comparisons for M85 VFV Luminas Tested with M85, and Gasoline Control Luminas Tested with Indolene

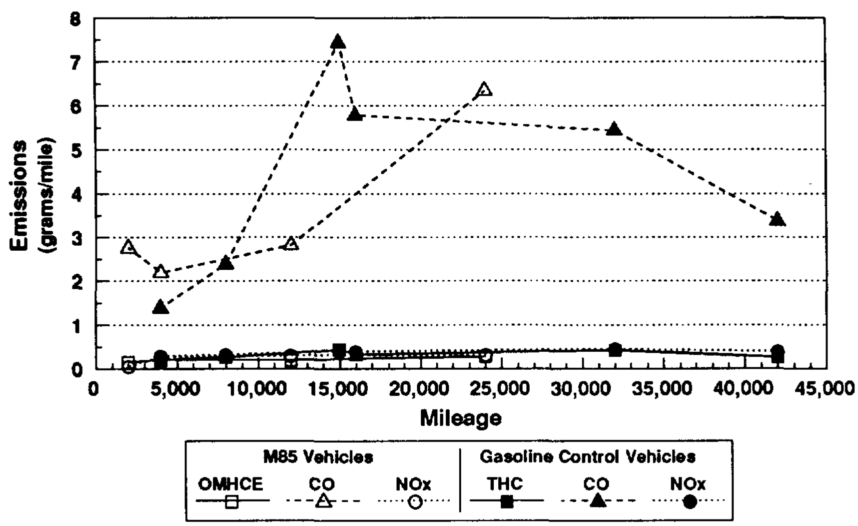


Figure 3-14. Emissions Comparisons for M85 FFV Tauruses Tested with M85, and Gasoline Control Tauruses Tested with Indolene

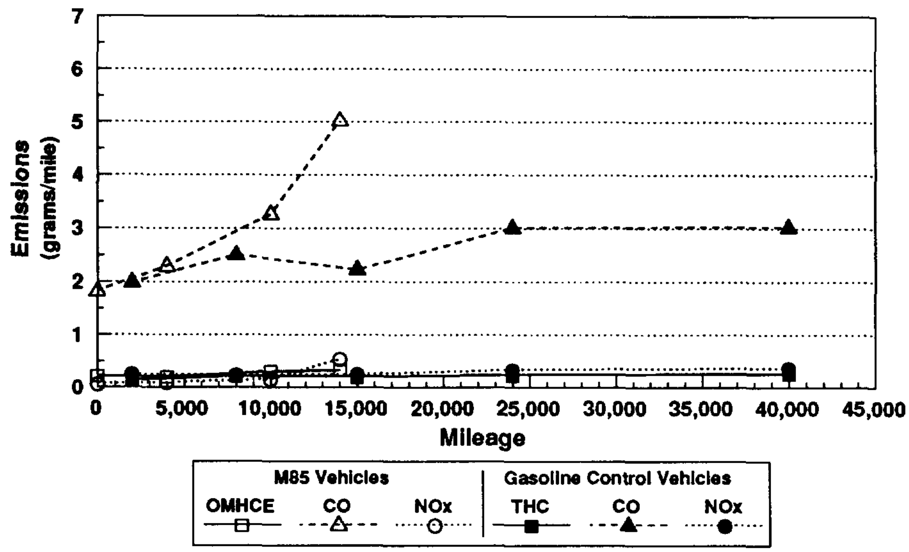
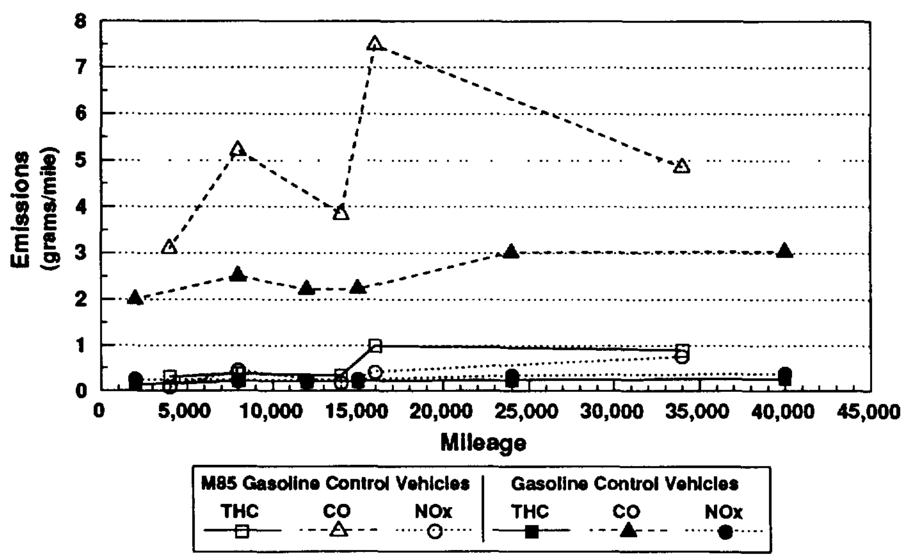


Figure 3-15. Emissions Comparisons for M85 FFV Control Tauruses and Gasoline Control Tauruses Tested with Indolene



both vehicle types are operated on gasoline. There is a modest growth, then leveling, of all three emission constituents for the gasoline control Tauruses. It is difficult to determine a trend in emissions for the M85 control Tauruses because of the substantial swing in direction (particularly for carbon monoxide emissions) between 14,000 and 16,000 miles. These differences come from results of testing different vehicles at the same Environmental Protection Agency laboratory and reflect the comments made earlier about the contributions to variability in emissions test data. In reviewing the data from those two mileage points, and as with the carbon monoxide data from Figure 3-13, no valid reason could be found to discard one or the other data sets. Further examples of the effect of emission data variability are illustrated in Figures 3-16 and 3-17 and Tables 3-6 and 3-7. In addition, it should be noted that improvements in emission levels were not observed in a number of cases where vehicle maintenance and/or repair were performed between emission tests. Figure 3-16 compares the range of carbon monoxide emission data for M85 flexible-fuel vehicle Tauruses tested with Indolene and M85 fuels.

Table 3-6 shows the differences between the average value and range of test data and the total spread from the minimum to the maximum test data values. Figure 3-17 and Table 3-7 present similar data for the M85 variable-fuel vehicle Luminas at 12,000 and 24,000 miles.

Note from Figures 3-8 and 3-10 through 3-15 that there are frequent occasions where carbon monoxide and hydrocarbon emissions exceed the current standards, and often within the range of 10,000 to 25,000 miles. As mentioned previously, normal test-procedure variability factors cannot account for either the wide range of observed emission values and the relatively high frequency of test data that exceed the standards. This is one of the major reasons why the DOE has significantly expanded the emission test portion of the Light-Duty Alternative Motor Fuels Program—to increase the precision of judgments about comparative emission trends among the alternative fuels being evaluated.

Of the Lumina test vehicles (representing a mix of the same vehicles used for exhaust emissions) used to develop evaporative emissions test data, only one vehicle test (an M85 variable-fuel vehicle Lumina tested with Indolene) failed to meet the maximum limit of 2 grams of hydrocarbons set by the Environmental Protection Agency for emission certification purposes. It is suspected that a problem may have occurred in that vehicle during that specific test because subsequent evaporative emission testing indicated results which were well below the 2-gram standard.

3.9 Operator Satisfaction/Driveability

For Phase I vehicles, the driveability information was recorded on the weekly survey form which summarizes the weekly operation of the participating vehicles. Vehicle driveability was recorded by the driver for each day of operation. Driver observations on idle quality, hesitation, hard starting, stalling after starting, and pinging were recorded. For Phase II vehicles, the vehicle driveability information were recorded on the data input form and mailed to the data collection contractor after every vehicle refueling. The type of driveability information recorded was the same as for Phase I.

Figure 3-16. Comparison of CO Emission Variability for M85 FFV Tauruses Tested with Indolene and M85

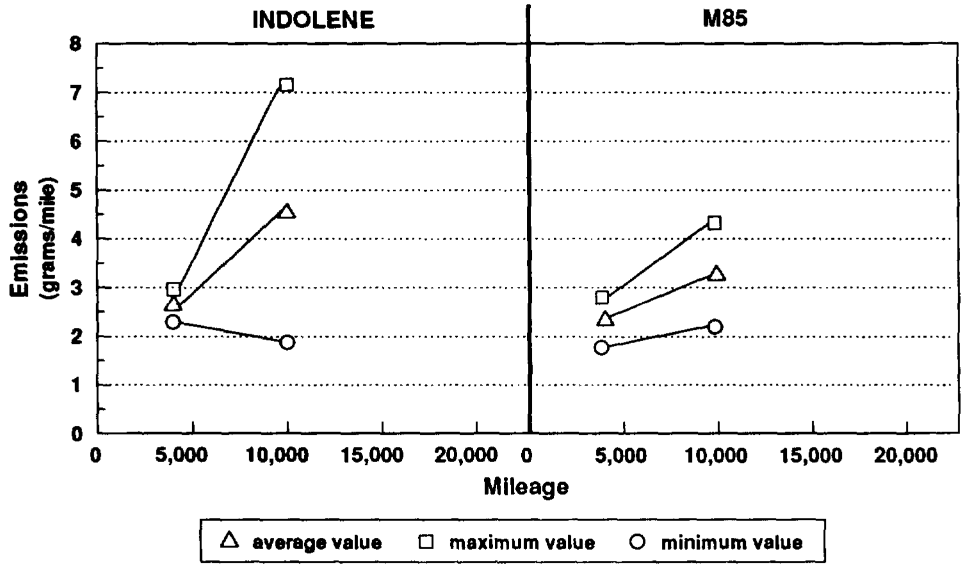


Figure 3-17. Comparison of CO Emission Variability for M85 VFV Luminas Tested with Indolene and M85

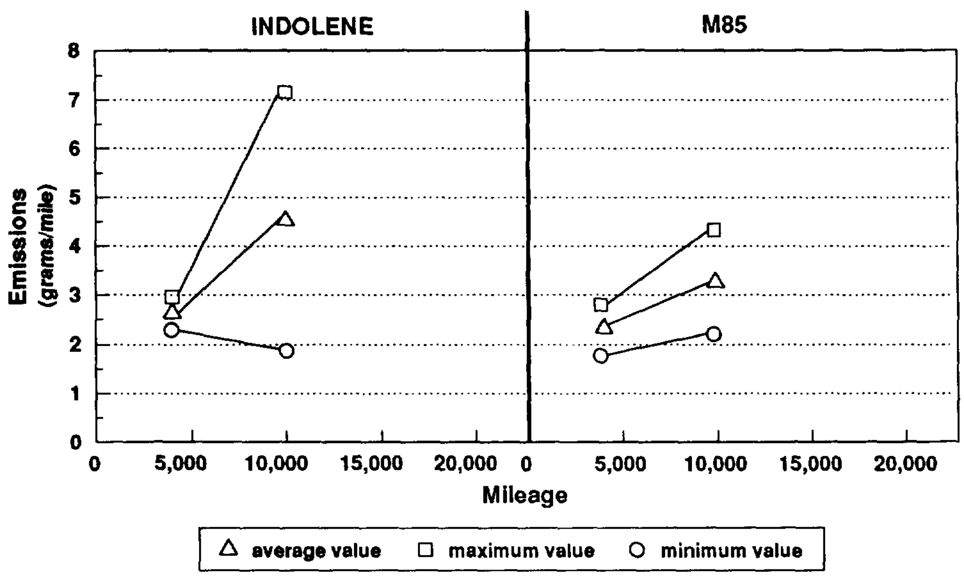


Table 3-6. Comparison of Carbon Monoxide Emission Data Variability for Indolene and M85 Test Fuels in M85 Tauruses

Test Fuel	Percent Difference between Lowest and Highest Values for CO Emissions at 4,000 Miles and 10,000 Miles			
	From Average to Min. or Max.		From Min. to Max.	
	4,000 mi.	10,000 mi.	4,000 mi.	10,000 mi.
Indolene	± 13	± 58	27	279
M85	± 22	± 32	57	95

Table 3-7. Comparison of Carbon Monoxide Emission Data Variability for Indolene and M85 Test Fuels in M85 Luminas

Test Fuel	Percent Difference between Lowest and Highest Values for CO Emissions at 12,000 Miles and 24,000 Miles			
	From Average to Min. or Max.		From Min. to Max.	
	12,000 mi.	24,000 mi.	12,000 mi.	24,000 mi.
Indolene	± 37	± 37	119	119
M85	± 91	± 74	2064	661

Since the beginning of vehicle operations, various driveability difficulties were reported on some of the vehicles, including rough engine idling, hesitation on acceleration, "check engine" light on, and engine stalling. Figure 3-18 presents the frequency distribution of driveability problems for Phase I vehicles by month, and shows that the problems per vehicle per month were the largest during fiscal year 1992. During this time period, the driveability problems that occurred with the M85 Ford Taurus were largely attributed to performance degradation of various unique components of the vehicle such as the EEC-IV engine microprocessor, fuel-sending unit, and fuel-pressure regulator. Upgrade kits were delivered to the participating authorized Ford service centers, and the upgraded hardware was installed on the vehicles exhibiting driveability problems.

The driveability problems that occurred with the M85 Chevrolet Lumina were largely attributed to performance degradation of the unique fuel injector and fuel-pump speed-controller components. A dealer service bulletin was issued in November 1991 to the participating authorized General Motors service centers, outlining the driveability problems, possible cause, and repair procedures (install new service calibration programmable read-only memory (prom) computer chip and fuel-pump speed controller). Repairs were performed on all 25 M85 Chevrolet Lumina vehicles participating in Phase I. Installation of upgraded hardware and the dealer service bulletins reduced the number of driveability problems experienced by these vehicles.

Analysis of Figure 3-18 indicates that the driveability difficulties reported per month appear to be declining significantly for the 1993 fiscal year. This reduction in driveability complaints is probably a direct result of the fuel-system updates. However, these vehicles still have a significantly higher rate of driveability problems when compared to both alternative fuel vehicles running on gasoline and conventional gasoline control vehicles.

Figure 3-18. Driveability Problems by Month

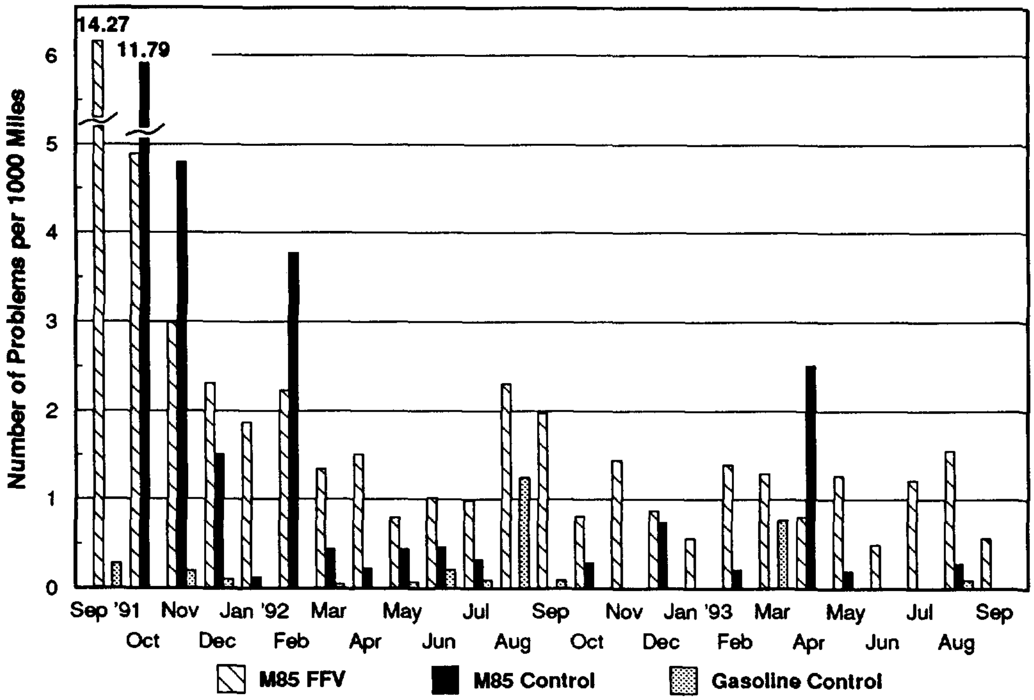


Figure 3-18 can also be examined to identify whether driveability problems exhibit seasonal variances particularly with respect to temperature. Due to the characteristics of M85 and its low volatility, an increase in cold-starting problems would be expected during the cold months. Although examination of the data suggest that a mild trend may exist, it cannot be statistically confirmed. As the driveability data set increases with the Phase II vehicles, next year's report should be able to present a more definitive analysis.

Figure 3-19 presents the same data on a mileage basis, plotting of the average number of driveability problems per vehicle which were experienced for each vehicle which completed each mileage interval. This graph indicates that driveability problems are experienced within the first 5,000 miles and for the variable-fuel Chevrolet Luminas peak at about 11,000 miles. Driveability problems for the Ford Taurus also are experienced within the first 5,000 miles and remain relatively constant to about 25,000 miles. For both vehicles, the flexible-fuel vehicles exhibit a greater frequency of driveability problems for most mileage intervals. Comparison between Figure 3-18 and Figure 3-19 indicates that the driveability problems have not diminished as dramatically as Figure 3-18 suggests.

In addition to the frequency of driveability problems, it is helpful to look at the relative frequencies of each driveability problem. Figure 3-20 shows the distribution of driveability problems for the Phase I methanol vehicles. The most common difficulties were hesitation, idle quality, and stalling in traffic. In nearly all cases, the vehicles running on M85 encountered many more driveability problems than the gasoline-fueled vehicles.

The Phase II compressed natural gas vehicles at Bakersfield, California, reported a very high number of driveability problems during fiscal year 1993. The relative distribution of these problems is shown on Figure 3-21. In this figure, the highest frequency of driver complaints are hesitation, pinging, hard starting, and lack of power.

For the Phase II project in El Paso, Texas, Figure 3-22 presents the number and type of problems reported from November 1992 to May 1993. This graphic dramatically illustrates the early driveability problems for this project. In addition, the dramatic drop in driveability problems corresponds to a high level of maintenance performed on these vehicles during this time period. Figure 3-24 in the next section presents a breakdown of the number and type of components that were replaced to correct these driveability problems.

3.10 Maintenance

Driveability problems and maintenance should be linked with a cause-and-effect relationship. Typically, the vehicle operator experiences a driveability problem which then prompts a maintenance response. If, however, the maintenance repair is unsuccessful and fails to solve the problem, the operator, after a number of attempts to correct the problem, may stop reporting the problem. Figure 3-23 plots the frequency of unscheduled fuel-system maintenance actions at progressive mileage intervals for both the M85 Taurus and M85 Lumina. Unscheduled maintenance for the conventional gasoline vehicles is not shown on this graph since only one fuel-system repair for eight conventional gasoline control vehicles was performed. This graph suggests that unscheduled fuel-system maintenance actions tend to decrease somewhat with accumulated mileage. This result seems to agree with the trends shown on Figure 3-18, although not to the same degree. However, when compared with Figure 3-19, there seems to be some contradiction. It appears that the cause-and-effect relationship between driveability and maintenance is not as strong as hypothesized. This may be due to the phenomenon outlined earlier where vehicle operators tire of bringing the vehicle in for service which only partially corrects the problem. It will take additional data from Phase II projects to determine, with statistical methods if, and to what degree, the vehicles are actually improving with regard to driveability and maintenance.

Figure 3-19. Phase I M85 and Gasoline Driveability Problems

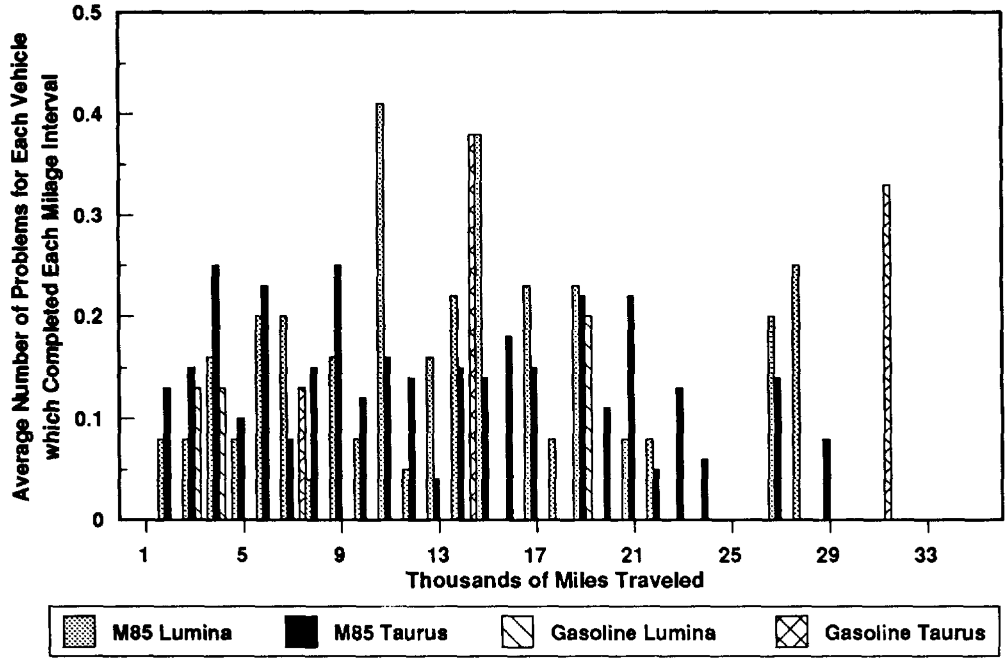


Figure 3-20. Driver-Reported Problems
Phase I Methanol Vehicles

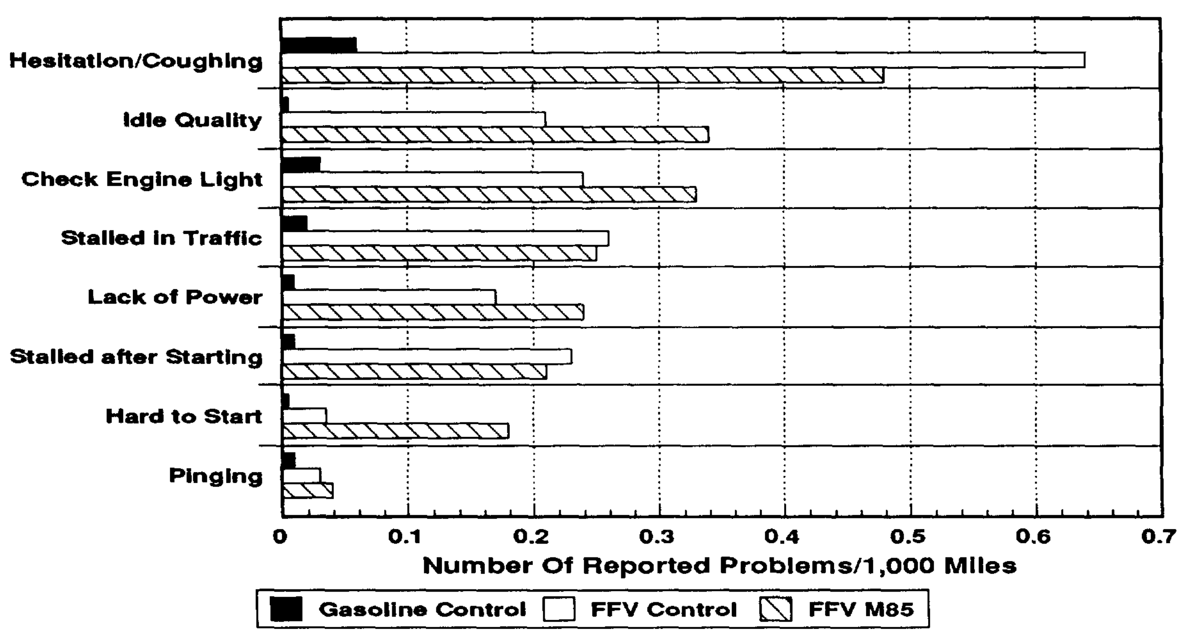


Figure 3-21. Driver-Reported Problems
Phase II CNG Vehicles at Bakersfield, California

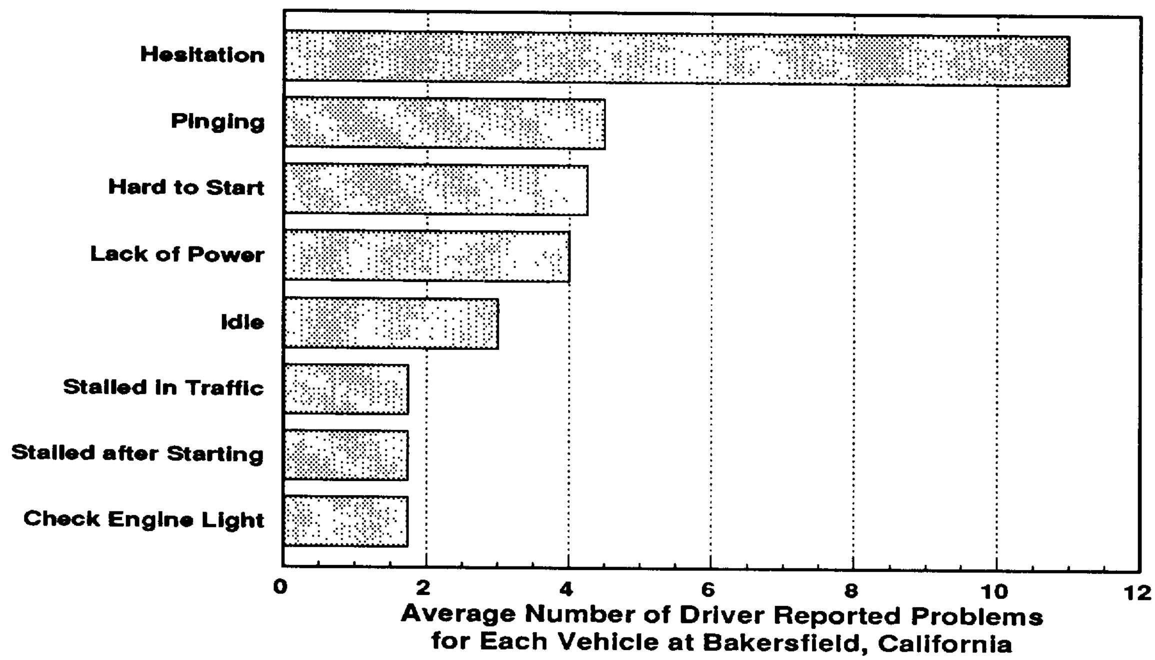
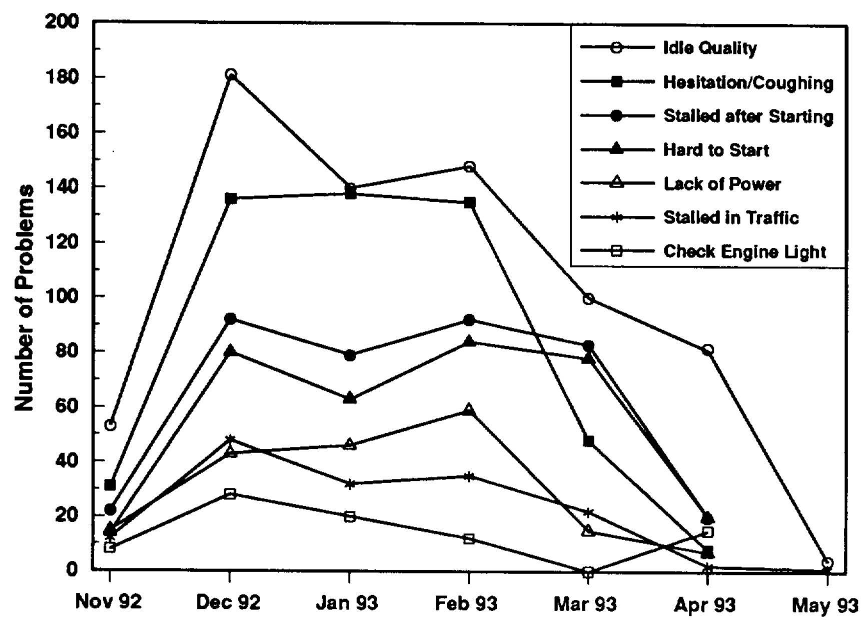
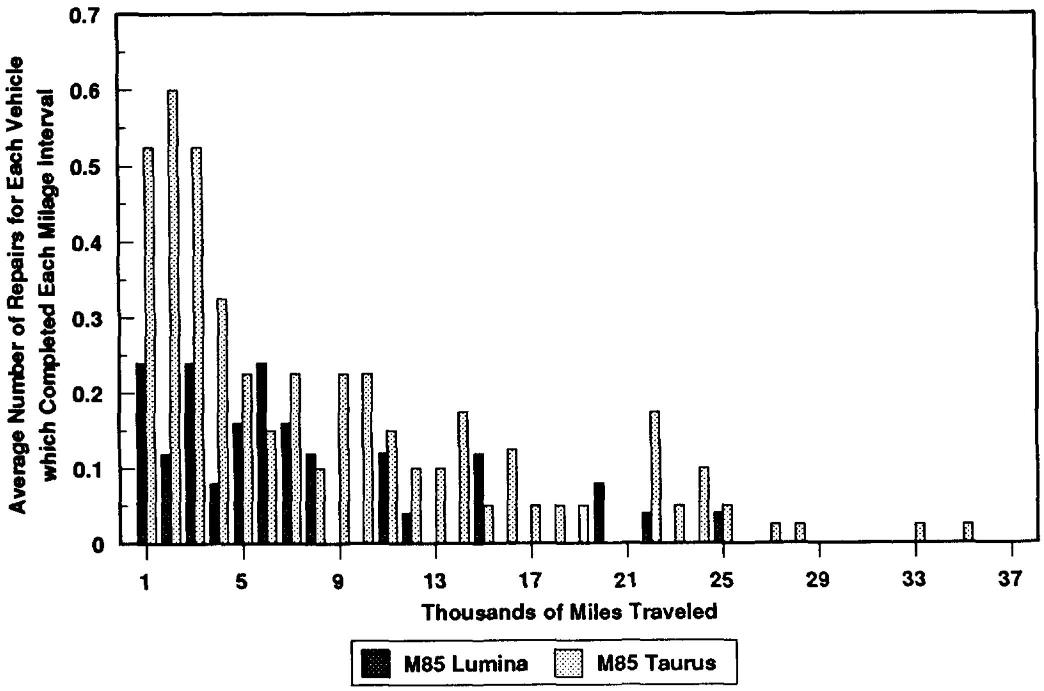


Figure 3-22. CNG-Reported Driveability Problems
at El Paso, Texas



Source: National Renewable Energy Laboratory

Figure 3-23. Phase I M85 Fuel System Repairs



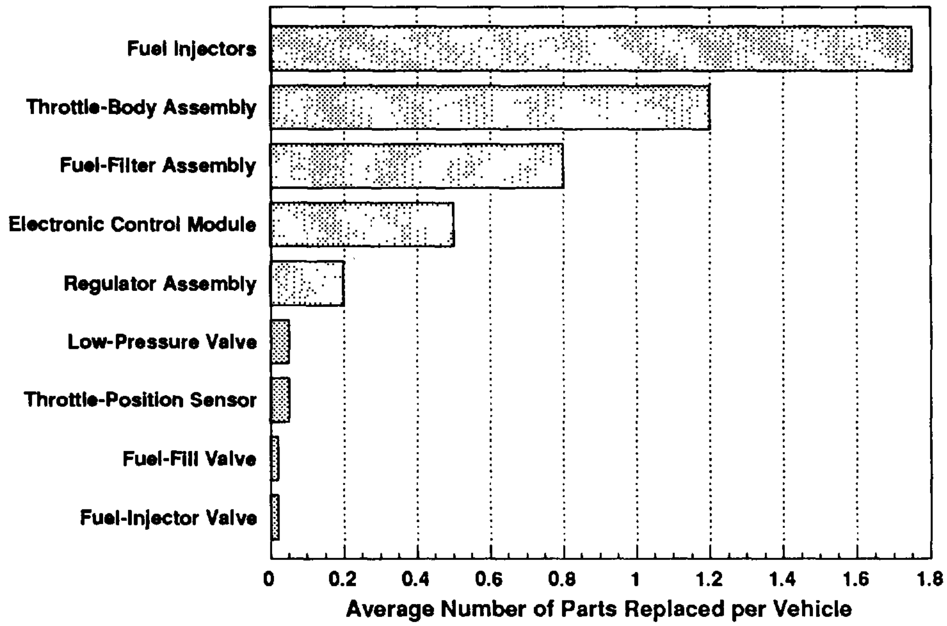
What can be reliably determined from Figure 3-23 is that alternative fuel vehicles have required more unscheduled fuel-system maintenance than the conventional gasoline vehicles.

The compressed natural gas C2500 pickups in the El Paso region have also experienced a high number of driveability problems which have, in turn, prompted a high number of maintenance actions. Figure 3-24 illustrates the frequency by which fuel-system components were replaced. Examining the data reveals that the most frequently replaced items are the fuel injectors, with an average of almost two sets of fuel injectors per vehicle. In addition, almost all of the vehicles have the throttle-body assembly replaced. The fuel-filter assembly was replaced on 75 percent of the vehicles, and about half of the vehicles had the electronic control modules replaced. For this project, the maintenance actions appear to have corrected the driveability problems.

3.11 Future Activities

Additional alternative fuel vehicles are planned to be added to the Light-Duty Alternative Motor Fuels Program in fiscal year 1994. Like the previous Phase I and Phase II projects, this project will be supported with full data collection and technical support services. In the near future, there are plans to add 196 additional vehicles and one additional site in Atlanta, Georgia, for a Phase III project.

Figure 3-24. CNG Fuel System Components
Which Were Replaced through September 30, 1993



In addition to the expansion of the light-duty projects, an emissions test plan has been developed for expanding the testing of the exhaust and evaporative emissions for these vehicles. The main aspects of the plan include:

- Six vehicle fuels including E85, E50, M85, M50, compressed natural gas, and reformulated gasoline (RFG).

- Combined emissions tests comprising a Federal Test Procedure test followed by duplicate 4-minute special tests (known as an IM240 test) used to approximate the Federal Test Procedure results. Emissions are measured for both the Federal Test Procedure and the IM240 portions.

- Testing of about 400 vehicles at five sites and 624 FTP/IM240 emissions tests to determine differences in exhaust and evaporative emissions.

- To the maximum extent practical, vehicles will be tested at the 4,000-mile mark to assure stable operation of the emissions control system. Following the initial emissions test, tests will be conducted at 10,000 miles and every 10,000 miles thereafter, or annually, whichever is more frequent. Testing will proceed for at least 3 years, after which specific vehicles from the project may be chosen for longer-term testing at higher mileage.

4.0 ALTERNATIVE FUELS TRUCK COMMERCIAL APPLICATIONS PROGRAM

4.1 Summary of Projects

Five alternative fuel-heavy duty vehicle projects are currently operating, involving a total of 130 vehicles:

- The Archer Daniels Midland Company, in cooperation with the Illinois Department of Energy and Natural Resources, is operating five line-haul tractors. Four of these vehicles operate on E95 (a mixture of 95 percent ethanol and 5 percent unleaded gasoline) and the other vehicle is a diesel baseline control vehicle.

- Vons Grocery Company, in cooperation with Acurex Environmental Corporation, is operating two line-haul tractors in California; one vehicle operates on compressed natural gas and the other vehicle is a diesel control vehicle.

- The New York Department of Sanitation is operating nine refuse haulers, with six of the vehicles being compressed natural gas vehicles and the other three are diesel baseline control vehicles.

- Hennepin County, Minnesota, is operating three snow plow/dump truck vehicles in the project. Two of the vehicles are operating on E95 and the third vehicle is a diesel baseline control vehicle.

- Federal Express, in cooperation with the South Coast Air Quality Management District, is operating 111 pickup and delivery-type vehicles in southern California. Twenty of these vehicles operate on propane, 20 operate on M85 (a mixture of 85 percent methanol and 15 percent unleaded gasoline), 21 operate on compressed natural gas, 21 operate on reformulated gasoline, two are electric vehicles, and the remaining 27 are baseline control vehicles operating on regular unleaded gasoline.

The locations for these vehicle projects and the type engines used for each of the alternative-fueled vehicles are described in Table 4-1, Section 4.1.3 of this report.

4.1.1 Participants

The National Renewable Energy Laboratory, located in Golden, Colorado, manages data collection activities of the alternative fuels truck commercial applications program. This program has projects which include the Illinois Department of Energy and Natural Resources/Archer Daniels Midland, Acurex/Vons Grocery Co., New York Department of Sanitation, and the South Coast Air Quality Management District/Federal Express Corporation.

The Trucking Research Institute has been under contract to the National Renewable Energy Laboratory to serve as a focal point in the commercial trucking industry for the advancement of alternative fuel use. The Trucking Research Institute is the research and educational arm of the American Trucking Association's Foundation, Inc., which is, in turn, the research arm of the American Trucking Association, the trucking industry's national trade association, with affiliated state associations in the 50 states and the District of Columbia.

The primary tasks in the Trucking Research Institute's subcontract are to catalog all existing Alternative Fuels Heavy-Duty and Medium-Duty Trucking Demonstrations; gather data from ongoing demonstrations, recognizing that such data may be incomplete, fragmented, and not standardized; provide incentives for new alternative fuel heavy-duty and medium-duty projects organized under a strict data collection protocol which includes baseline control vehicles operating on conventional fuels; and publicize truck-related alternative fuel information throughout the industry and government with a quarterly newsletter and periodic industry presentations. The new demonstration projects bring together vehicle and engine manufacturers, fuel-system designers, fuel suppliers, interested government agencies, and commercial motor carrier host fleets, all of whom contribute to the program.

New alternative fuel truck demonstrations are aimed at encouraging truck original equipment manufacturers and engine manufacturers to design, produce, and warranty vehicles designed to operate on alternative fuels. Wherever possible, emphasis is given to producing dedicated alternative fuel vehicles, rather than dual-fuel vehicles. All vehicles in the new demonstrations are to be emissions tested periodically by West Virginia University's Transportable Emissions Testing Laboratory during a 3-year data collection period.

The Trucking Research Institute has coordinated the start of a new demonstration project which involves 20 city "package cars" (medium duty) operated on compressed natural gas by United Parcel Service, Inc., at its Landover, Maryland (Washington, D.C., metro area) terminal. State and local government demonstrations involve two new projects being coordinated by the Trucking Research Institute. Included are two sets of ethanol (E85), a mixture of 85 percent ethanol and 15 percent unleaded gasoline, heavy-duty road maintenance and truck/snowplows operating in Hennepin County, Minnesota, and the State of Nebraska Department of Public Roads.

4.1.2 Vehicles

A variety of different truck types are being used in the Alternative Fuels Truck Commercial Applications Program. Examples of several of the types of vehicles used in the demonstration projects are illustrated in Figures 4-1 through 4-4.

4.1.3 Locations

As shown in Figure 4-5, the various truck projects are located at a number of different locations throughout the United States. Table 4-1 outlines the locations, type of vehicles, and engine technologies used in the Alternative Fuels Truck Commercial Applications Projects.

Figure 4-1. Ethanol-Fueled Tractor Operated by Archer Daniels Midland in Decatur, Illinois

Figure 4-2. One of New York City's Compressed Natural Gas-Powered Refuse Haulers

Figure 4-3. A Propane-Powered Federal Express Delivery Truck is Part of the CleanFleet Program in Los Angeles

Figure 4-4. This Compressed Natural Gas Over-the-Road Truck is Operated by Vons Companies, Inc., in California

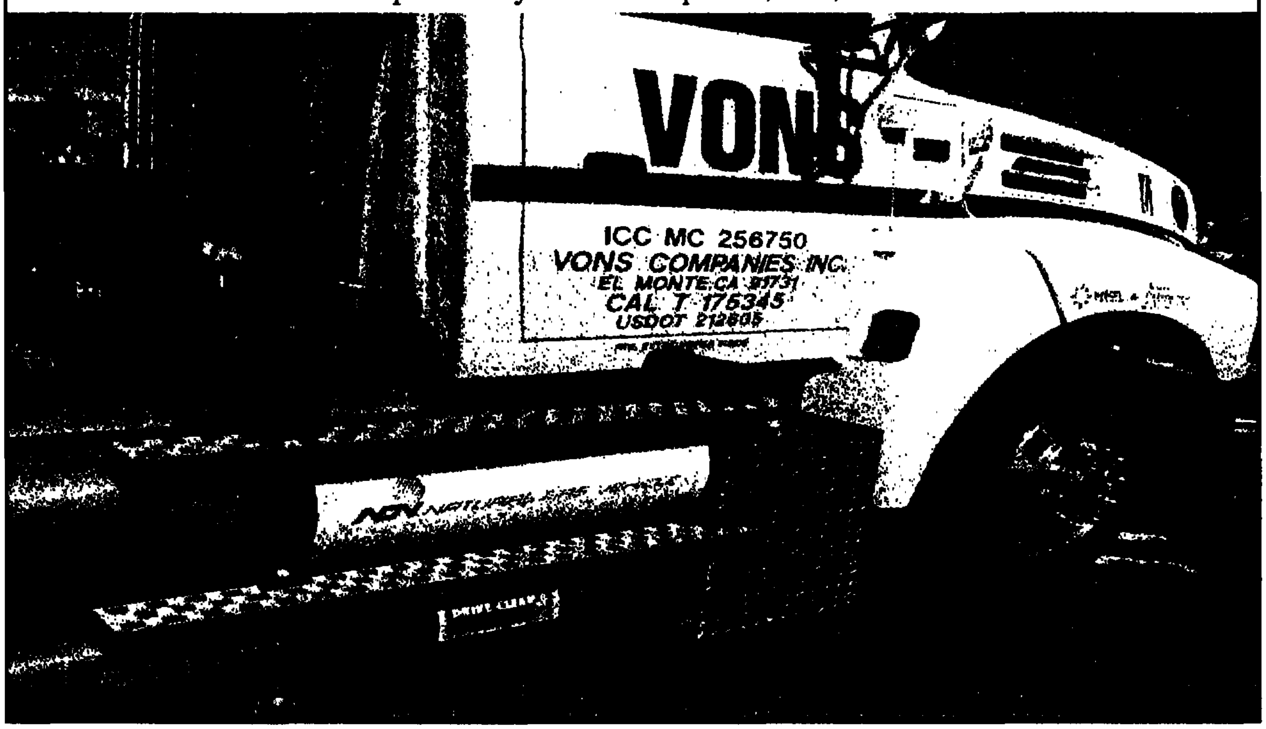
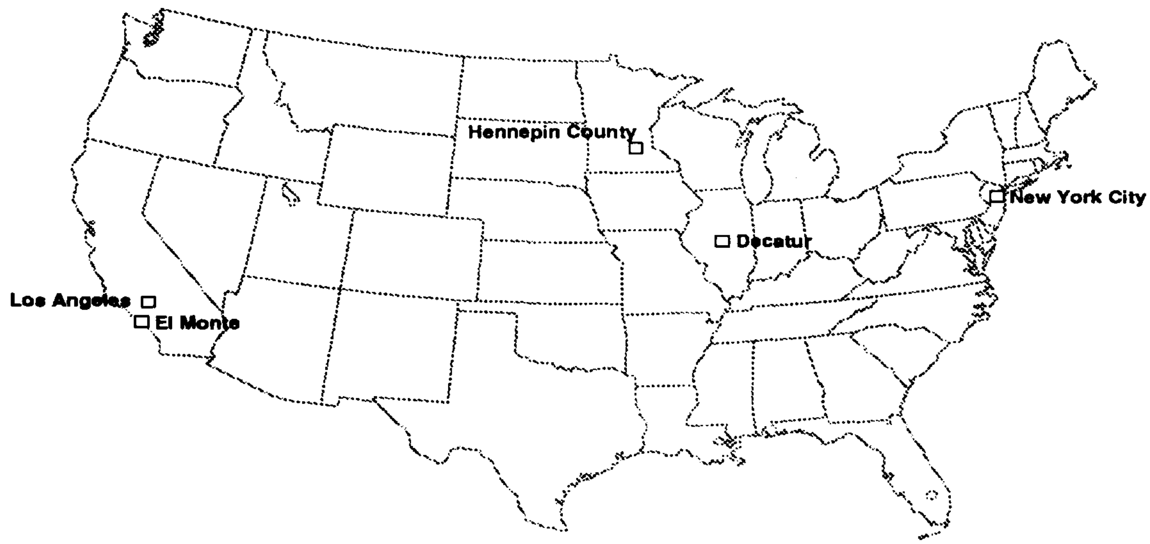


Figure 4-5. Map Showing Heavy-Duty Fleet Locations



4.1.4 Technical Characteristics of Vehicles

The technical characteristics of the various truck commercial engines and fuel systems are outlined in Appendix A. It should be noted that the technology levels of the engines in these projects are somewhat behind the levels of the latest models since technology improvements are progressing rapidly.

4.1.5 Infrastructure Support

Refueling facilities are lacking in some of the project locations, causing fleet operators to provide their own refueling facilities. For some compressed natural gas vehicles, the fleet operators have made arrangements to use the local gas utility companies' compressed natural gas refueling facilities. In certain locations, such as New York City or the Los Angeles area, some public refueling facilities are available. See Section 2.0 of this report for locations of alternative fuel public refueling facilities.

Similarly, due to the limited number of alternative fuel heavy-duty vehicles in the program, authorized repair facilities have not been set up to service the heavy-duty vehicles, except for the Federal Express project. Although the Federal Express vehicles are classified as medium-duty vehicles, the engine and fuel system technologies used in these vehicles are similar to those used for light-duty vehicles. Therefore, authorized repair facilities listed in the light-duty vehicle section of this report can make the repairs. However, in the heavy-duty vehicle locations, most all of the repair and maintenance work is done at the fleet operators' own repair facilities.

Table 4-1. Participants, Number and Type of Vehicles, and Location of Vehicles

Participants	Truck Type	Number of Vehicles and Fuels		Engine	Location
		Baseline	Alternative		
Archer Daniels Midland Corp./Illinois Department of Energy and Natural Resource/	Line-Haul Tractor	1-Diesel	4-Ethanol (E95)	Detroit Diesel 6V92	Decatur, Illinois
Von Grocery Co./Acurex	Line-Haul Tractor	1-Diesel	1-Compressed Natural Gas	Caterpillar 3406	El Monte, California
New York Department of Sanitation	Refuse Hauler	3-Diesel	6-Compressed Natural Gas	Cummins L10	New York City, New York
Trucking Research Institute/Hennepin County, Minnesota	Snowplow/ Dump Truck	1-Diesel	2-Ethanol (E95)	Detroit Diesel 6V92	Hennepin County, Minnesota
Federal Express/South Coast Air Quality Management District	Pick-up and Delivery	27-Unleaded Gasoline (All Locations)	20-Propane 20-Methanol (M85) 21-Compressed Natural Gas 21-Reformulated Gasoline 2-Electricity	Various Original Equipment Manufacturer V6, Inline Six, and V8	Rialto, Santa Ana, Irvine, Los Angeles, and Culver City, California

4.2 Performance

4.2.1 Mileage Accumulation

Mileage accumulation data are being collected for all of the heavy-duty projects. Data analysis of this information is underway.

The Federal Express vehicles for which these data have been recorded went into service starting July 1992. Figure 4-6 shows that these vehicles have accumulated a total of

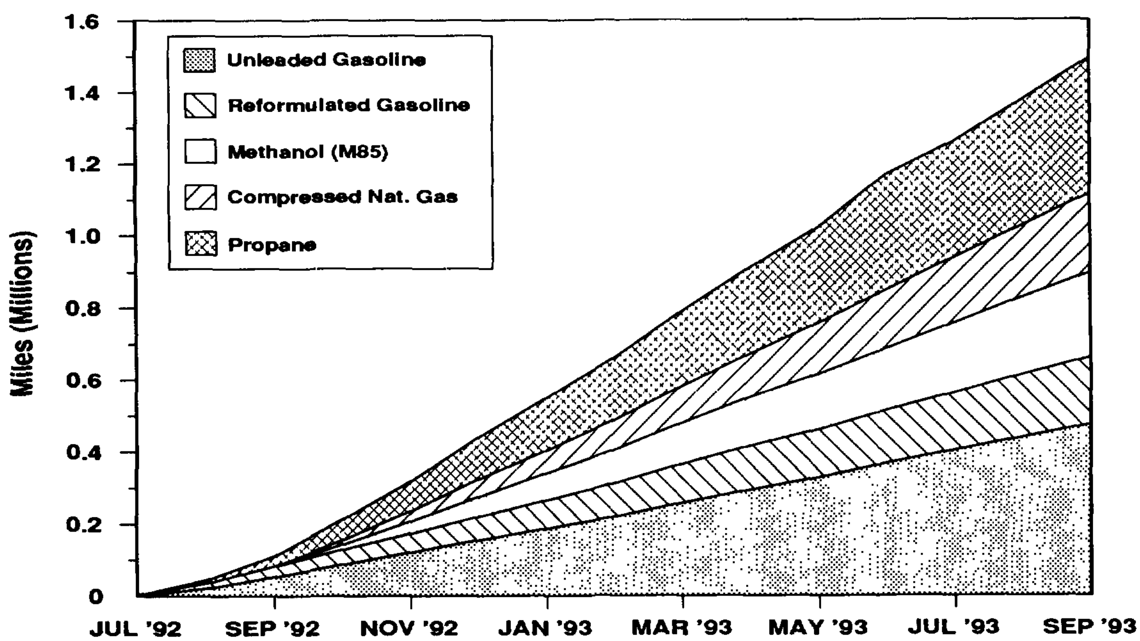
1,497,735 miles in 14 months of service. The total accumulated mileage for each fuel type was 474,363 for the regular unleaded gasoline-powered vehicles; 188,568 for the reformulated gasoline-powered vehicles; 233,241 for the M85-powered vehicles; 219,049 for the compressed natural gas-powered vehicles; 378,620 for the propane-powered vehicles; and 3,894 for the electric-powered vehicles. Due to the short range and limited mileage for the electric vehicles, the electric vehicle miles are not shown in Figure 4-6.

The New York City Department of Sanitation project accumulated over 20,000 miles in fiscal year 1993 with six compressed natural gas trucks. The Archer Daniels Midland project has accumulated 662,261 miles with four E95 and one diesel control vehicle.

4.2.2 Challenges of Operations

As with all new technologies that are introduced into service, there are problems that must be solved and corrected. The trucks fueled with ethanol sometimes experience cold-starting difficulty during cold weather due to the low volatility and high heat of vaporization of the ethanol fuel. The engines used in the ethanol trucks were originally designed for methanol which has different cold-start characteristics than ethanol. Engine developments are expected to decrease the cold-starting difficulties experienced by the current ethanol engines.

Figure 4-6. Cumulative Miles for Alternative Fuel and Baseline Vehicles in the Federal Express Fleets



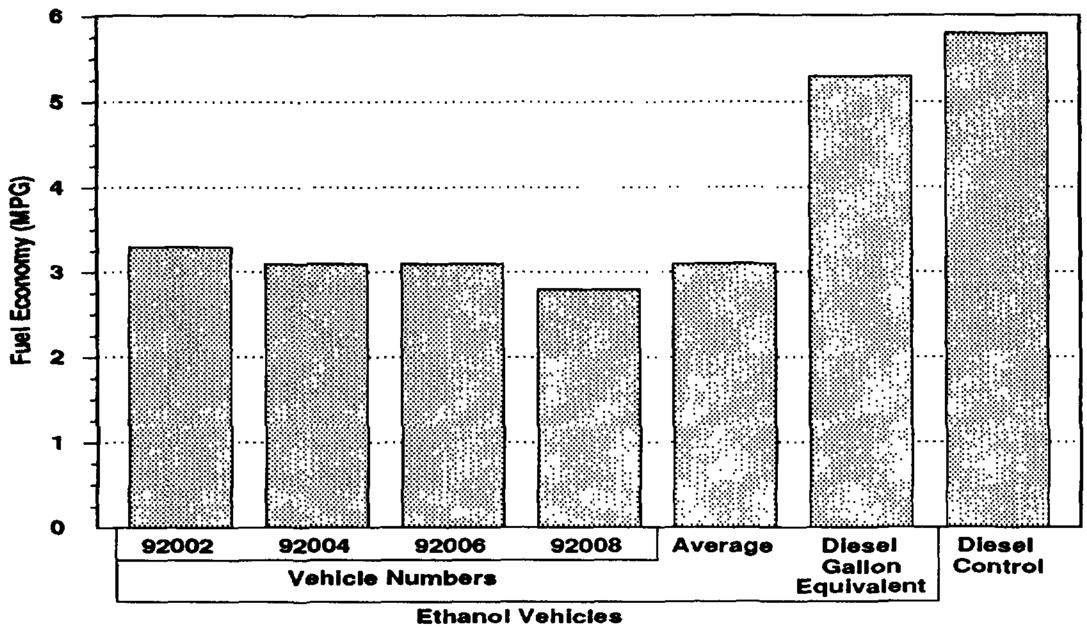
4.2.3 Efficiency

Fuel-economy data for alternative and conventional fuels are being collected and analyzed for all of vehicles participating in the program. Because a portion of the truck project operations are in the early stages, some fuel-economy data cannot be reported at this time due to quality assurance measures. Therefore, fuel economy will be reported and discussed for those fleets where quality fuel-economy data are available.

The on-road fuel economy for the four ethanol line-haul trucks in the Archer Daniels Midland project as compared to the diesel-fuel baseline control vehicle is shown in Figure 4-7. The diesel gallon equivalent fuel economy for the four different ethanol vehicles range from 4.6 to 5.5 miles per gallon. The vehicle-to-vehicle fuel economy appears to be fairly consistent considering that this is on-road fuel economy and there can be variations in the weight of the load hauled, duty cycle, etc., which can significantly affect fuel economy. The fuel economy of the ethanol vehicle's expressed as miles per diesel gallon equivalent is about 8 percent less than that for the diesel control vehicle.

Variations in fuel economy for on-road vehicles may be due to both differences in operational duty cycle and engine technology. Engine technology differences are to be expected when considering that diesel engines have been under development for decades whereas the ethanol engine is in the early stages of development. Once the ethanol engine is fully developed, it should have essentially the same diesel gallon equivalent fuel economy of the diesel engine with the additional advantages of lower oxides of nitrogen and particulate emissions.

Figure 4-7. On-Road Fuel Economy for the Ethanol Tractors in the Archer Daniels Midland Fleet as Compared to the Diesel Control Vehicle



Emissions and fuel economy have been measured on two ethanol trucks and one diesel control truck from the Archer Daniels Midland project. These tests were conducted by West Virginia University, using the Transportable Emissions Laboratory, shown in Figure 4-8. For these tests, each vehicle was operated on the Central Business District (CBD) transit bus cycle. Emissions are expressed as grams per mile (the emissions results will be reported in a later section of this report) and fuel economy is calculated as miles per gallon. When alternative fuel was used, fuel economy was calculated as diesel gallon equivalent miles per gallon. When these tests were conducted, an appropriate driving cycle for trucks had not been developed. Therefore, the transit bus cycle was used for testing these trucks on the chassis dynamometer. A dynamometer testing cycle to be used in future truck testing is currently under development and will be reported as a part of next year's activities.

The fuel economy as measured during the emissions testing for two of the Archer Daniels Midland ethanol trucks and one diesel control vehicle is shown in Figure 4-9. The relatively low volumetric fuel economy of the ethanol vehicles compared to the diesel vehicles is to be expected because of the lower energy density of ethanol. However, when the ethanol fuel economy is expressed as diesel gallon equivalent miles per gallon, the fuel economy is nearly the same for both fuels. The ethanol engines used in these trucks are Detroit Diesel Corporation compression-ignition engines that have been modified from the Detroit Diesel Corporation's methanol-based engine buses.

The variation in the on-road fuel economy for the six compressed natural gas trucks used in the New York Department of Sanitation project shown in Figure 4-10 ranges from

Figure 4-8. West Virginia Mobile Emission Testing Facility

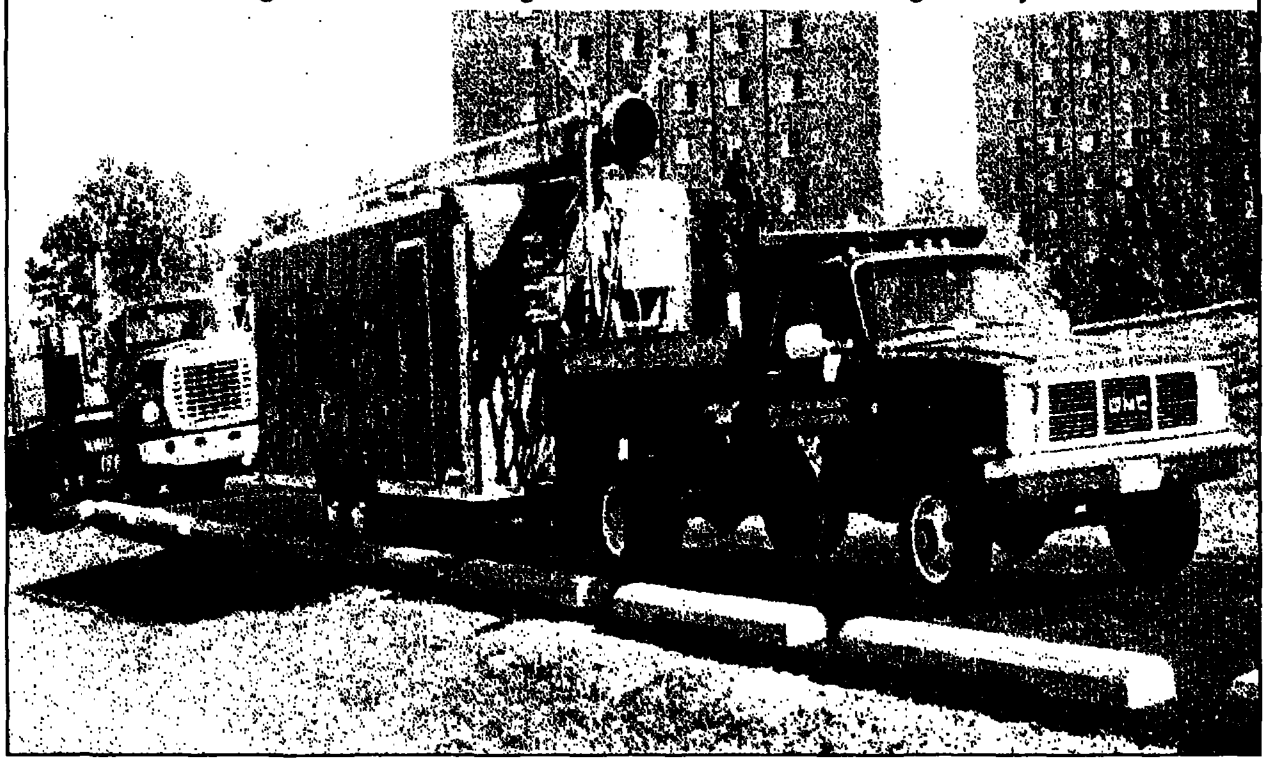


Figure 4-9. Fuel Economy Measured During Emissions Testing of Ethanol Tractors as Compared to a Diesel Control Vehicle

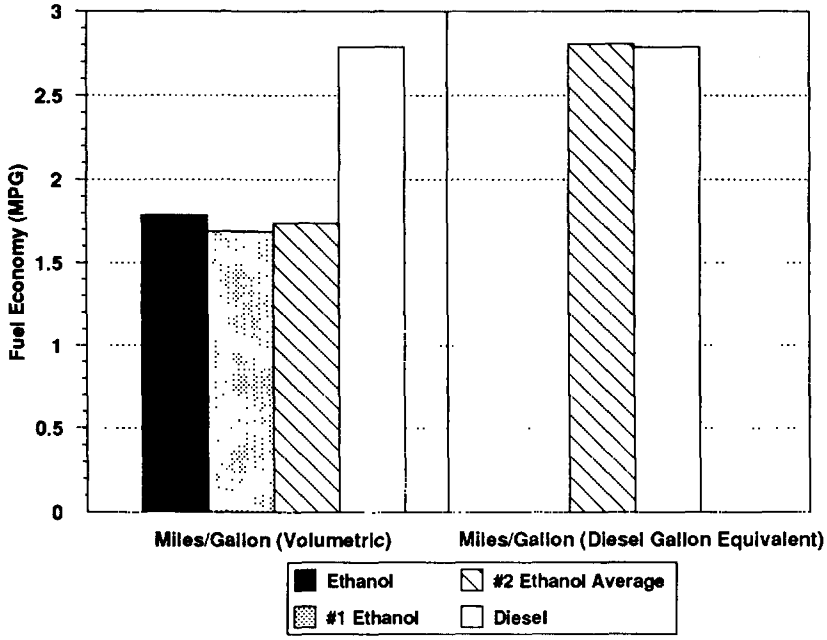
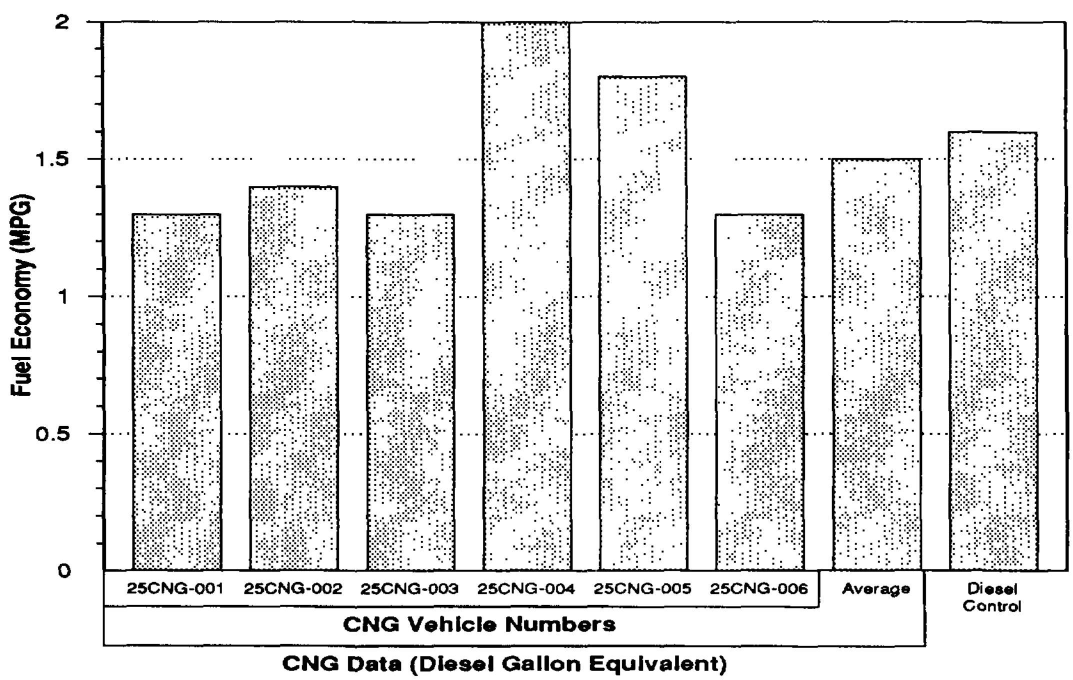


Figure 4-10. On-Road Fuel Economy for the Compressed Natural Gas Refuse Haulers in the New York Department of Sanitation Fleet as Compared to a Diesel Control Vehicle



1.3 to 2.0 diesel gallon equivalent miles per gallon. This amount of variation is not unusual for these type of engines. Although the Cummins L10 natural gas engine is fairly well developed, it is a throttled spark-ignition engine, and fuel economy can be significantly affected depending on the duty cycle. A throttled natural gas engine will have much lower fuel economy for stop-and-go driving when compared to the same or similar vehicle operating on a highway cycle. On the other hand, the fuel economy of diesel vehicles, which are unthrottled engines, will show much less variation in fuel economy throughout the different driving cycles. The variation in fuel economy for the natural gas vehicles is likely to be due to a difference in on-road driving cycles, rather than an engine-to-engine variation. The average on-road diesel gallon equivalent fuel economy of the natural gas vehicles is about seven percent less than the on-road fuel economy of the diesel baseline control vehicle. Again, this lower fuel economy for the natural gas vehicles (as compared to the diesel vehicles) is expected because the natural gas engines are throttled and suffer from throttling losses at part load, whereas the diesel engines are unthrottled, and do not suffer from these throttling losses.

Two of the New York Department of Sanitation compressed natural gas trucks were tested for emissions using the West Virginia University Transportable Emissions Test Laboratory, but no corresponding baseline diesel control vehicle was tested. The fuel economy was found to be nearly equal, 2.6 and 2.7 miles per diesel gallon equivalent, respectively. As the project continues, data will be collected for similar diesel control vehicles to establish a baseline for comparison.

The Federal Express project involves the evaluation of several alternative fuels, including compressed natural gas, propane, M85, and reformulated gasoline, as well as two electric vehicles. Fuel economy for the electric vehicles will not be discussed here because, due to their range limitations, these vehicles were operated on a much different driving cycle from the other vehicles, making comparisons difficult. To minimize the effect of the various driving cycles, fuel-economy comparisons are based on gasoline control vehicles of the same type operating in similar environments as the test vehicles.

Federal Express operations are typical of most pickup and delivery services. The vehicles are driven between 20 to 80 miles per day on fixed routes for 5 or 6 days each week. Most vehicles make dozens of stops per day. However, the results from the Federal Express project should not be generalized and applied to all types of fleet operations. Applications that involve heavier payloads or other types of duty cycles can produce different results.

To compare on-road fuel economy between gaseous fuels, methanol, and gasoline, fuel economy is expressed in terms of gasoline gallon equivalent miles per gallon. A gasoline gallon equivalent of an alternative fuel is equal to the amount of alternative fuel that has the same energy content as one gallon of a reference unleaded gasoline.

Statistical treatment of the data was used to account for variations in duty cycles within the Federal Express operations. The delivery vans were randomly assigned to delivery routes that varied from less than 20 to more than 80 miles per day. Regression analysis was used to establish the relationship between vehicle fuel economy and both the average daily mileage and the average number of delivery stops per day. Estimates of on-road fuel economy for the various fuels were calculated from the regression model using the predicted on-road fuel economy for a typical duty cycle of 40 miles per day. These estimated on-road fuel economy results are presented in Figures 4-10 through 4-13. These data were analyzed and produced by Battelle, Columbus, Ohio and reported in "Vehicle Fuel Economy - First 5,000 Miles," Statistical Analysis Report No. 2, November 1993.

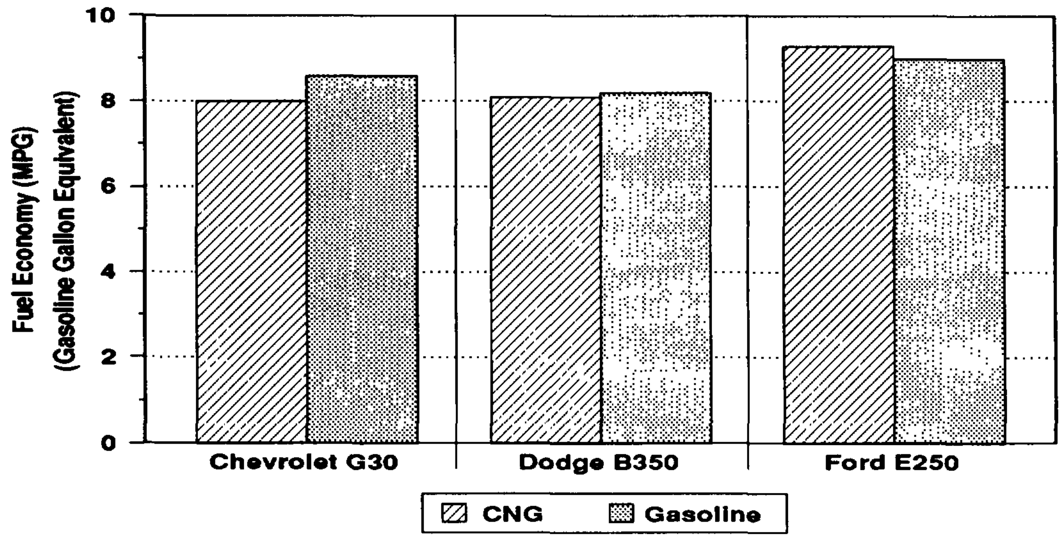
The fuel economy of compressed natural gas and gasoline vehicles for Chevrolet G30, Dodge B350, and Ford E250 vehicles is shown in Figure 4-11, indicating that the compressed natural gas vehicles have slightly lower on-road gasoline gallon equivalent fuel economy than the baseline gasoline control vehicles for the Chevrolet and Dodge vehicles, and slightly higher on-road fuel economy for the Ford vehicles. Compressed natural gas vehicles should give essentially the same gasoline gallon equivalent fuel economy as gasoline vehicles for two reasons. First, due to the higher octane number of compressed natural gas, the engine compression ratio of the compressed natural gas engine can be increased to improve efficiency. Secondly, during cold-start and warmup, compressed natural gas engines can be started without mixture enrichment as needed for gasoline engines, and the relatively leaner operation during the cold-start and warmup phases of the driving cycle results in improved fuel economy. However, this improvement can be offset to some extent by the extra weight of the compressed natural gas fuel tanks.

The on-road fuel economy of propane and gasoline vehicles for both Chevrolet G30 and Ford E250 vehicle is shown in Figure 4-12. These results indicate that the propane vehicles have a lower on-road fuel economy than the baseline gasoline control vehicles. As with compressed natural gas vehicles, propane vehicles should have essentially the same or better gasoline gallon equivalent fuel economy as gasoline vehicles for the same reasons that were discussed earlier. The differences in on-road fuel economy between propane and gasoline for this particular project could be due to the fact that these propane vehicles are probably not as optimized as their gasoline counterparts.

The on-road fuel economy data for unleaded gasoline and M85 for Ford E250 vehicles (Figure 4-13) indicate that the gasoline gallon equivalent on-road fuel economy for the M85 vehicles is slightly lower than that for the gasoline control vehicles. A slight improvement in the efficiency is expected for the methanol vehicles because of the high latent heat of vaporization of methanol as compared to gasoline. When methanol vaporizes in the intake manifold, the high latent heat of vaporization causes charge cooling, tending to reduce throttling losses at part load, which should result in a slight improvement in efficiency when compared to gasoline. As the development of methanol vehicles continues, any on-road fuel economy deficiency for methanol vehicles should disappear. The small difference in fuel economy for the vehicles shown here is not statistically significant.

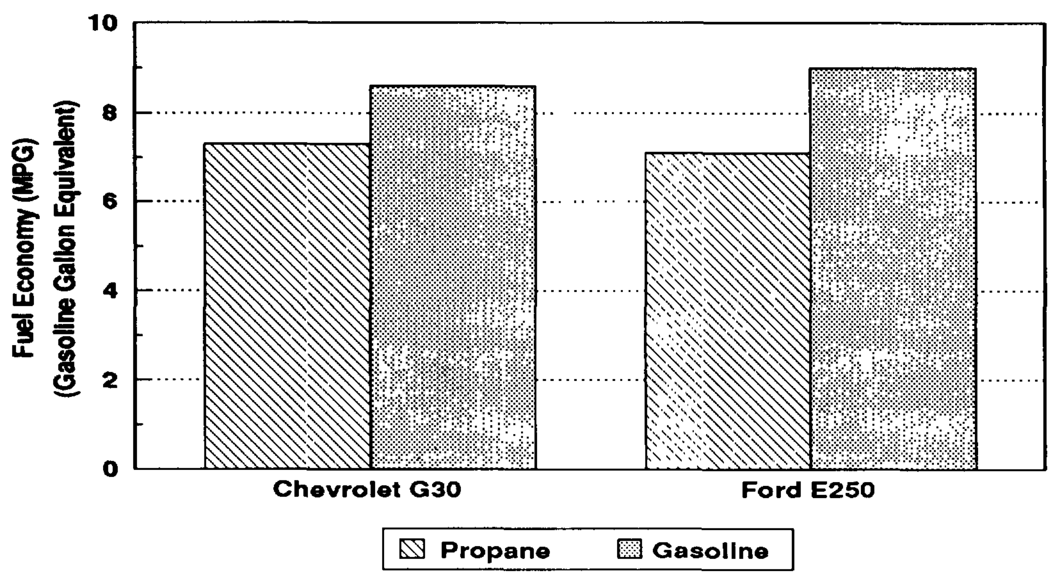
The on-road fuel economies for reformulated gasoline and regular unleaded gasoline are compared in Figure 4-14 for the three different types of vehicles, indicating that the gasoline gallon equivalent on-road fuel economy for reformulated gasoline was slightly higher than that for regular unleaded gasoline in the Dodge vehicles and slightly lower for the Chevrolet and Ford vehicles. The gasoline gallon equivalent fuel economy between reformulated gasoline and regular gasoline should be similar for any given vehicle.

Figure 4-11. On-Road Fuel Economy of Compressed Natural Gas and Gasoline Chevrolet G30, Dodge B350, and Ford E250 Vehicles Operating at the Los Angeles, California, Site



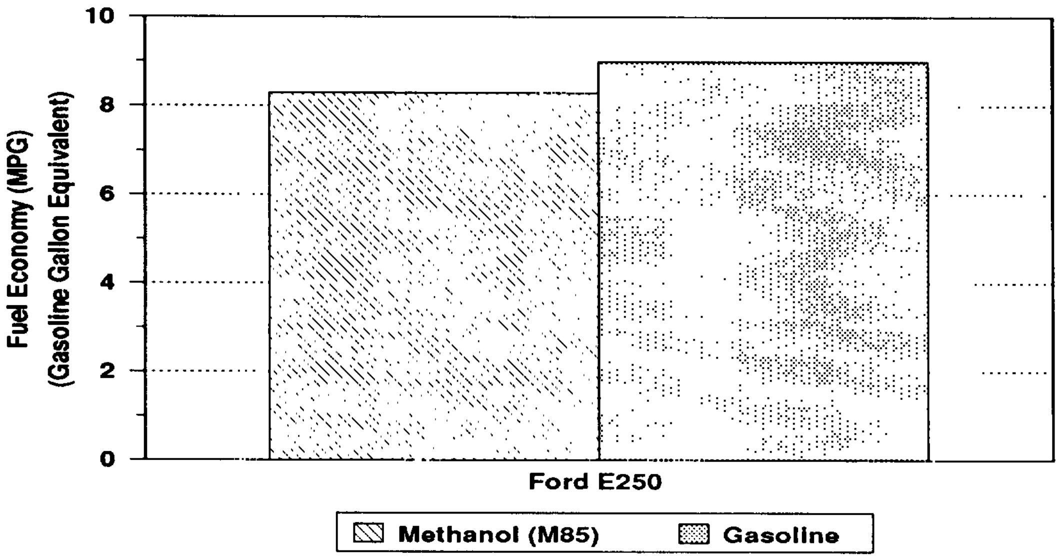
Source: Battelle Memorial Institute

Figure 4-12. On-Road Fuel Economy of Propane and Gasoline Chevrolet G30 and Ford E250 Vehicles Operating at the Rialto, California, Site



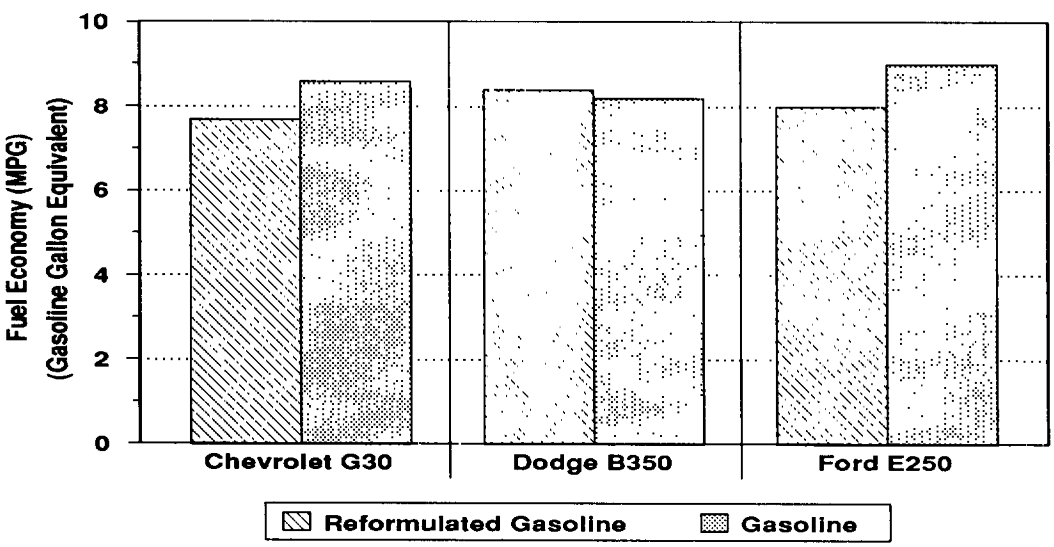
Source: Battelle Memorial Institute

Figure 4-13. On-Road Fuel Economy of M85 and Gasoline Ford E250 Vehicles Operating at the Santa Ana, California, Site



Source: Battelle Memorial Institute

Figure 4-14. On-Road Fuel Economy for Reformulated Gas and Regular Unleaded Gas Used in Chevrolet G30, Dodge B/350, and Ford E250 Vehicles Operating at the Los Angeles, California, Site



Source: Battelle Memorial Institute

4.2.4 Emissions

As mentioned earlier, emissions and fuel economy have been measured on two ethanol trucks and one diesel control truck from the Archer Daniels Midland Company project and two compressed natural gas trucks from the New York City Department of Sanitation. These tests were conducted by West Virginia University using the Transportable Emissions Laboratory. Each vehicle was operated on the Central Business District (CBD) transit bus cycle, with emissions expressed as grams per mile.

For methanol-fueled engines, organic material hydrocarbon equivalent (OMHCE) emissions is used rather than hydrocarbon, where organic material hydrocarbon equivalent is determined by summing the masses of residual hydrocarbon, adjusted for values of methanol and formaldehyde which eliminates the oxygen portion of these emissions, making organic material hydrocarbon equivalent comparable on a mass basis to the hydrocarbon emissions measured from diesel engines.

Shown in Figure 4-15 are the carbon monoxide (CO), oxides of nitrogen (NO_x), and organic material hydrocarbon equivalent (OMHCE) emissions from the three trucks tested. In this case, no carbon monoxide emission data are available for the diesel control vehicle. The lower oxides of nitrogen levels for the ethanol vehicles when compared with the diesel vehicles confirm the results from earlier DOE-sponsored research work. The organic material hydrocarbon equivalent emissions from the ethanol engine are significantly higher than the hydrocarbon emissions from the diesel control vehicles. This indicates that further development on the emissions control systems of ethanol engines will be required. However, it should be noted that ethanol hydrocarbon emissions are less reactive and less toxic than the equivalent amount of hydrocarbon emissions from diesel fuel. Shown in Figure 4-16 are particulate, aldehydes, and unburned ethanol emissions for the Archer Daniels Midland trucks. No particulate emissions data are available for the E95 trucks. However, based on previous research work, particulate emissions are expected to be low for ethanol as compared to diesel fuel. The emissions of aldehydes and unburned ethanol for the E-95 trucks were high.

The emissions from the two New York City Department of Sanitation compressed natural gas trucks are shown in Figure 4-17; no emissions data are available on diesel control vehicles. The data indicate that the emissions from two identical compressed natural gas trucks can be markedly different, particularly in carbon monoxide and hydrocarbon emissions. Both of these trucks have original-equipment Cummins L10 natural gas engines. However, natural gas engines for heavy-duty vehicles are still early in their development and a certain amount of engine-to-engine variability of emissions is to be expected. As the development of natural gas engines progresses, engine-to-engine variability should decrease.

Shown in Figure 4-18 are the particulate emissions for the two New York City Department of Sanitation compressed natural gas trucks when operated over the CBD transit bus cycle. The particulate emissions from natural gas engines are almost entirely due to consumption of lubricating oil within the engine because natural gas does not produce particulates when combusted. Lubricating oil consumption also contributes to the particulate emissions of diesel engines using diesel fuel. Diesel engine manufacturers have reduced

Figure 4-15. CO, NO_x, and OMHCE/HC Emissions from Ethanol and Diesel Heavy-Duty Line-Haul Trucks

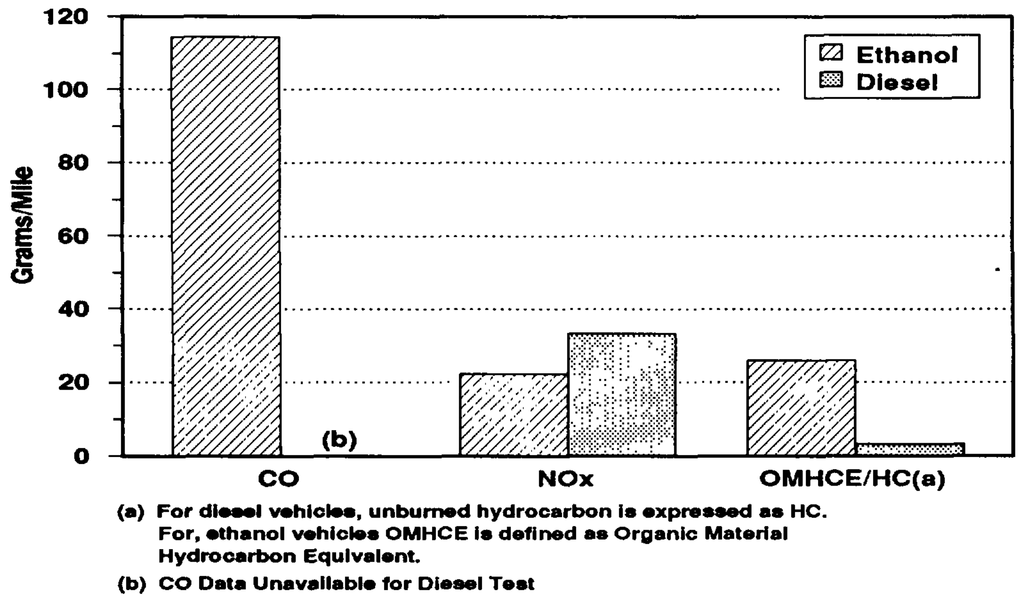


Figure 4-16. Particulate, Aldehydes, and Unburned Ethanol Emissions for Ethanol and Diesel Line-Haul Trucks

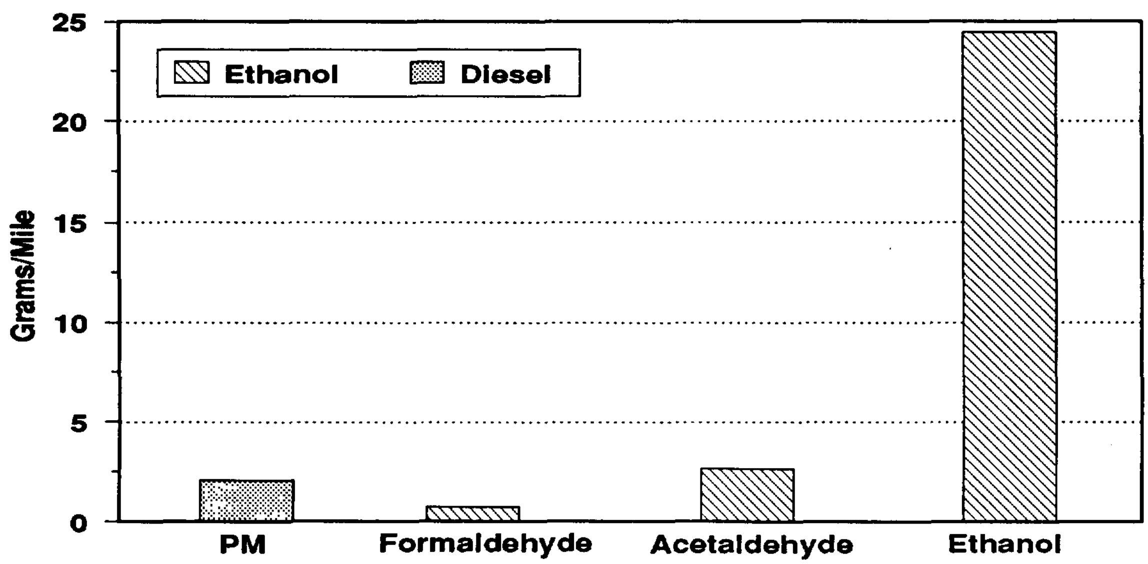


Figure 4-17. Gaseous Emissions from Two Compressed Natural Gas Refuse Hauler Trucks

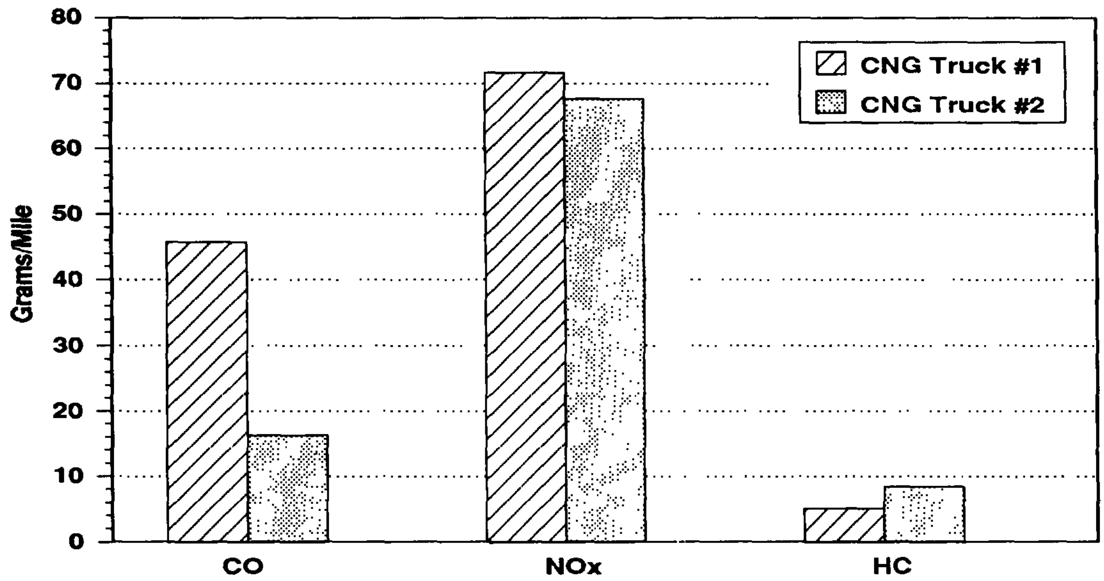
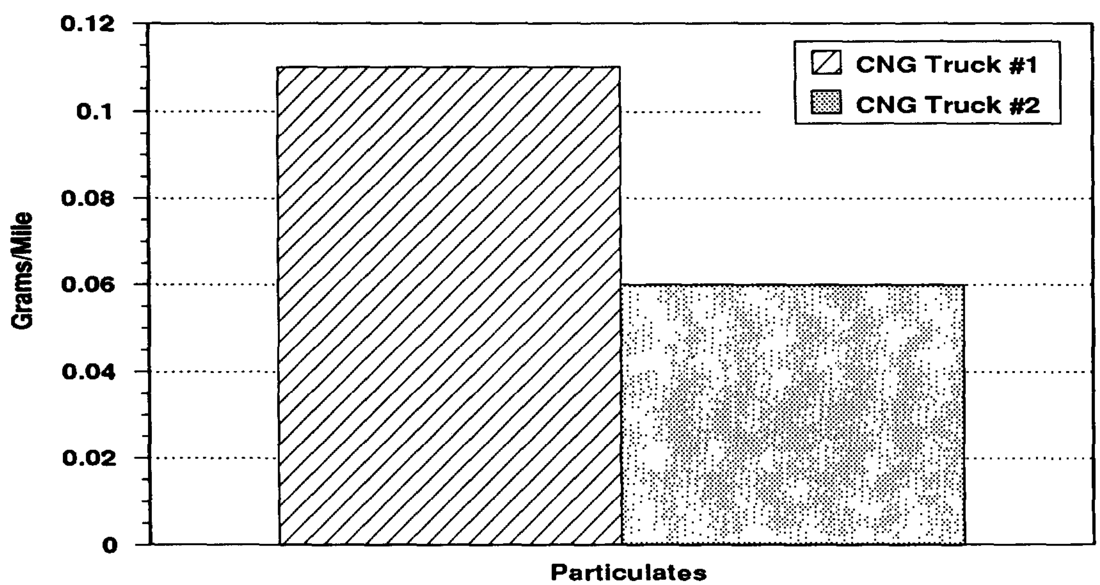


Figure 4-18. Particulate Emissions for Two Compressed Natural Gas Refuse Hauler Trucks



lubricating oil consumption significantly in recent years and further reductions will be difficult since it is not feasible to eliminate lubricating oil consumption using current engine technology. Further reductions in natural gas engine particulate emissions could come from optimized lubricating oil formulations and more advanced emissions aftertreatment devices. Particulate reduction in natural gas engines is expected to be achieved by evolutionary design improvements to reduce lubricating oil consumption. As the project continues, data will be collected for similar diesel control vehicles to establish a baseline for comparison.

Thirty-six Federal Express vehicles are being tested at the California Air Resources Board emissions laboratory. Emissions tests are planned three times during the 24 month demonstration as the vehicles accumulate mileage. The first set of tests included duplicate measurements of exhaust emissions. This first set of tests was conducted November 1992 through July 1993 as each vehicle reached at least 4,000 miles. In September 1993, the second round of emissions tests began on the same vehicles. Measurements of both exhaust and evaporative emissions are to be made. Data analyses of these emissions results from the Federal Express project are currently in progress and will be reported in next year's report.

4.2.5 Durability, Maintenance, and Reliability

Maintenance and reliability data are being collected on all of the heavy-duty truck projects and will appear in future reports. Durability of the alternative-fueled engines will be assessed and reported at the end of the demonstration with detailed inspections of two disassembled engines from each project location. In the Federal Express project, oil consumption is being recorded by Federal Express employees, and oil samples are being collected for chemical analysis with each oil change. As of September 30, 1993, a total of 421 oil samples had been analyzed. Nearly all of the vehicles have had a minimum of four oil changes. Results of the oil analyses will be reported in future technical reports and made available to industry and other interested parties. Any problems identified by the oil analyses as related to alternative fuels will be reported to ensure that corrective actions can be taken in by engine design changes and/or reformulation of lubricating oils.

As with all new systems, a number of maintenance and reliability problems have occurred with some of the alternative fuel vehicles. For the Federal Express propane vehicles, several problems associated with fuel-system electronic components, fuel control valves, vacuum lock-off valves, false activation of "check engine" lights, engine stalling, and computer software have surfaced. The manufacturer of the fuel system has been working, and continues to work, with Federal Express to correct these problems by replacing components and upgrading the related systems.

Problems associated with the Federal Express compressed natural gas vehicles included engine stalling, leakage of high voltage from ignition coils in some Chevrolet vehicles, and contamination of pressure regulators with lubricating oil (apparently from the natural gas refueling compressors). Corrective actions are being taken to eliminate these problems.

For the Federal Express M85 vehicles, one Ford vehicle had a small fire in the engine compartment. There were no injuries and only minor damage occurred to the vehicle. Ford is investigating the cause of the fire, which seems to have started near the cold-start injector. This vehicle was out of service for 2 weeks during September 1993.

The Federal Express vehicles operating on reformulated gasoline have not experienced any significant problems.

4.2.6 Operating Costs

Operating cost data are being collected for all of the medium and heavy duty vehicle projects. Analyses of these data are underway and will appear in later reports.

4.3 Medium- and Heavy-Duty Truck Projects Coordinated by the Trucking Research Institute

In the Trucking Research Institute's effort to catalog existing alternative fuel heavy-duty and medium-duty vehicles, 26 different projects that operate 387 vehicles on alternative fuels were identified. Of the 387 vehicles, 207 operate on compressed natural gas, 166 operate on liquefied petroleum gases, 7 operate on liquefied natural gas, 6 operate on methanol, and 1 operates on ethanol. Data have been collected from 19 of the 26 projects and provided to the National Renewable Energy Laboratory.

To date, the number of existing projects from which to gather data is limited. Data acquisition has been widely variable because of the unstandardized data tracking and the wide variety of duty cycles represented. Medium- and heavy-duty trucks operate over various duty cycles, ranging from pick-up and delivery in congested urban areas, long-distance over-the-road operations, and rural and urban road maintenance. A number of the existing alternative fuel vehicle projects are better characterized as experiments rather than vehicle demonstrations. Furthermore, none had defined their driving cycles in terms of speed *versus* time. Also, no common maintenance procedures nor systems for tracking maintenance costs have been developed. Therefore, it is very difficult to make direct comparisons among fleet experiences. For the alternative fuel truck projects that did start prior to the Alternative Motor Fuels Program, the most available and useful type of information is anecdotal. The Trucking Research Institute has gathered and cataloged most of the available data and continues to track those projects that are still underway. This information is provided to the National Renewable Energy Laboratory on a periodic basis.

4.3.1 Experience with Existing Alternative Fuel Vehicles

The alternative fuel trucks in the demonstrations that began before the Alternative Motor Fuels Program included package delivery, local delivery, LNG tanker, line haul, coal hauler, utility, garbage packer, refuse hauler, and logging trucks. Gross-vehicle-weight ratings for these vehicles ranged from 10,000 to 80,000 lbs. There are no operational cost, maintenance, fuel economy, or emissions data available from which to base conclusions about the operational characteristics of these alternative fuel vehicles. The only information available are subjective comments about the driveability of the vehicles. Anecdotal driveability comments about the vehicles included excellent, good, satisfactory, quiet and smooth, good power but poor acceleration, power loss, good acceleration but engine stalls;

and slow acceleration response. For the one ethanol vehicle, all injectors were replaced four times, glow plugs and controller were replaced three time; and driveability problems required numerous attempts to reprogram the engine controller to solve these problems. Given that alternative fuel engines were in the early stages of development when these demonstrations started, it is not surprising that significant operational problems occurred. Much work on alternative fuel engine development has been accomplished since these existing alternative fuel projects were put into place. These improvements are reflected in some of the bus demonstrations that are reported on in a later section of this report.

4.4 Future Activities

Three new truck demonstration projects will begin in the near future. One project will begin operations in Hennepin County, Minnesota, and will operate on E95. Two ethanol heavy-duty road maintenance and truck/snowplows will begin operation with the State of Nebraska Department of Public Roads. The United Parcel Service will begin operating compressed natural gas-powered package vehicles in the near future. These projects account for a total of 25 alternative fuel vehicles. In addition, data will be collected from six standard control vehicles in these projects, providing a baseline for comparison. Data concerning accumulated miles, fuel economy, maintenance, reliability, and operating cost, for these vehicles will be collected in a structured standardized format to permit statistically valid comparisons. Emissions tests will be conducted periodically on these vehicles with the West Virginia University Transportable Emissions Laboratory. Data from all participating vehicles will be sent to National Renewable Energy Laboratory's Alternative Fuels Data Center.

Financial and in-kind contributions are being made by industry and other participants. As an example, for the State of Nebraska ethanol project, the contributors are Hennepin County, Minnesota; Archer Daniels Midland; Minnesota Corn Growers; Nebraska Department of Roads; Nebraska Energy Office; Midwest Grain Products; Trucking Research Institute; and the United Parcel Service. The total contributions of industry and other participants results in nearly a 50-50 cost share between the Federal government and industry for these projects.

4.4.1 Planned New Demonstrations

Several compressed natural gas vehicle projects are planned for operation in California. These demonstrations will be set up by Acurex Environmental Corporation with cooperation from a number of host sites. Data will be collected from these operations and will be entered into the National Renewable Energy Laboratory's Alternative Fuels Data Center.

The Trucking Research Institute is actively working toward bringing several other commercial alternative fuel heavy-duty projects into operation. These projects include:

(1) Seven original equipment manufacturer heavy-duty refuse vehicles operating on liquefied natural gas vehicles manufactured by Mack Trucks, Inc.

(2) A city delivery heavy-duty project in southern California using a liquefied natural gas vehicle manufactured by Ford Motor Company, and using a Cummins "B"-series engine.

(3) A soy diesel (biodiesel) project using heavy-duty (80,000 gross vehicle weight) trucks with a variety of engines engaged in agricultural commodity hauling in Iowa and South Dakota.

(4) A heavy-duty project using liquefied natural gas-powered line-haul trucks in Louisiana.

(5) Urban pick-up and delivery by food-product and utility companies vehicles using medium-duty Ford F-700 vehicles with original equipment manufacturer compressed natural gas engines.

Data will be collected from all of these future projects under a strict data collection protocol which includes baseline control vehicles operating on conventional fuels. All data collected from these projects will be submitted to the Alternative Fuels Data Center at the National Renewable Energy Laboratory.

5.0 ALTERNATIVE FUELS BUS PROGRAM

The Alternative Fuels Bus Program includes transit buses as well as school buses. The transit bus and the school bus demonstration projects will be discussed in two separate sections of this report.

5.1 Transit Buses

5.1.1 Summary of Projects

The National Renewable Energy Laboratory collects data on alternative fuel and diesel control buses from two separate transit bus projects and stores the resulting data in the Alternative Fuels Data Center. The first project, sponsored by DOE, involves the collection of detailed operational, maintenance, and emissions data from five carefully selected transit agencies across the United States. The transit agencies were selected based on the following criteria:

- The availability of new alternative fuel buses that have new original-equipment engines for fuels such as compressed natural gas, liquefied natural gas, pure methanol (M100), and E95 (a mixture of 95 percent ethanol and 5 percent gasoline). The program goal was to have ten buses of each fuel/engine technology split between two transit agencies.

- The availability of identically equipped control vehicles with the exception of the fuel used.

- Cooperation of the transit agency in supplying detailed data.

The second project, sponsored by the U.S. Department of Transportation's Federal Transit Authority, provides a more general data base on most of the alternative fuel transit buses in service throughout the United States. Data are generated on the types, quantities, locations, and mileage accumulations for all of the alternative fuel buses in service at major transit agencies across the country. DOE's role for both projects is to collect data on emissions, fuel economy, and other operational characteristics for selected alternative fuel buses and to compare these data with similar data from diesel buses that are currently in service.

5.1.1.1 Participants

The National Renewable Energy Laboratory is responsible to collect data from the various transit bus operational sites, analyze the data, store the data in the Alternative Fuels Data Center, and make the data available to the industry, transit bus agencies, and other interested parties. Other participants in the program include the Federal Transit Authority, various State and local governments, transit bus agencies, engine manufacturers, and bus manufacturers.

5.1.1.2 Vehicles

In the DOE bus project, a total of 78 transit buses are operating at five locations. An additional project is being established in New York and a biodiesel project is planned for St. Louis, Missouri. Of the 78 buses already operating, 5 are operating on methanol (M100), 10 are operating on ethanol (E95), 10 are operating on compressed natural gas, 10 are operating on liquified natural gas, 13 are diesel buses equipped with particulate traps, and 30 are diesel control buses. The alternative fuel engines in the current projects are manufactured by Detroit Diesel Corporation and Cummins Engine Company. Included in the current projects are buses manufactured by Bus Industries of America (Orion), Flxible, Mercedes, and Transportation Manufacturing Corporation (TMC). In the Federal Transit Authority's alternative fuel bus program, 1,163 alternative fuel buses are in service at various locations across the country.

5.1.1.3 Locations

The transit bus project locations that are a part of the DOE sponsored project are given in Table 5-1, along with the number of buses, the various engine/fuel technologies, and bus manufacturers. Figure 5-1 shows the locations of both the DOE and the U.S. Department of Transportation Federal Transit Authority projects.

5.1.1.4 Technical Characteristic of Vehicles

The technical characteristics of the various transit bus engines and fuel systems are outlined in Appendix A. It should be noted that the technology levels of the engines in these projects are somewhat behind the levels of the latest models because technology improvements are progressing rapidly.

5.1.1.5 Infrastructure Support

Due to the nature of transit bus operations, the use of public refueling stations is generally not practical, and refueling facilities are usually located at the transit agency property. Due to the high capital cost of installing alternative fuel refueling facilities, some of the transit agencies have made arrangements to use the local gas utility company's natural gas refueling facilities. For compressed natural gas buses, about half of the transit agencies use gas utility company refueling facilities, while the others use their own facilities. Almost all of the transit agencies with liquefied natural gas buses have provided their own refueling facilities.

Due to the limited number of transit buses and their specialized characteristics, public facilities authorized to repair and maintain alternative-fueled vehicles are generally not used. The various transit agencies are generally set up to repair their own vehicles. In the case of alternative fuel buses, certain mechanics and repair personnel are specially trained so that they can repair and maintain the alternative fuel equipment.

Table 5-1. Number, Location, and Description of Transit Buses in the DOE Program

Engine/Fuel Technology								
Agency Location	Engine	M100	E95	LNG PING[1]	CNG SI[2]	Diesel w/Trap	Diesel Control	Bus
Houston	DDC 6V-92			10			5	40 ft Mercedes
Miami	DDC 6V-92 Cummins L10	5			 5	5	5 10	40 ft Flxible
Minneapolis	DDC 6V-92		5			5	5	40 ft Gillig
Peoria	DDC 6V-92		5			3		35 ft TMC
Tacoma	Cummins L10				5		5	40 ft Orion
Totals		5	10	10	10	13	30	

[1] Pilot-Injection Natural Gas
[2] Spark-Ignition

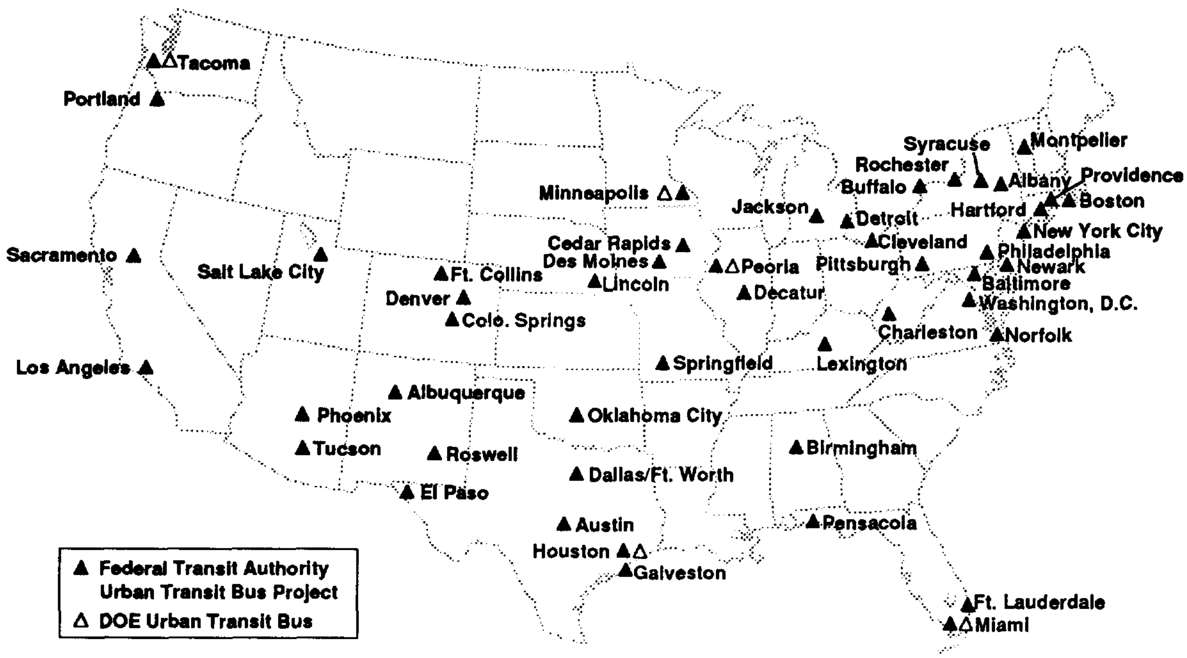
5.1.2 Transit Bus Operations

For the purposes of this report, it is impractical to include results from every transit bus project from which data are being collected. Therefore, results from selected representative projects that are operating buses on compressed natural gas, liquified natural gas, methanol, and ethanol will be used. The representative projects were chosen on the basis of completeness of the available data and of the representativeness of bus operations for other locations. The majority of the vehicle performance analysis has been generated for the vehicles in the earlier Department of Transportation project. It should be noted that because these programs have been in place for a while, the technology levels of these vehicles are behind the technology levels of the DOE/NREL-sponsored program vehicles.

5.1.2.1 Compressed Natural Gas Buses

Compressed natural gas bus operations from New York State, which are part of the project sponsored by the Federal Transit Authority, represent a cross-section of transit agencies at various locations across one state and are fairly representative of compressed

Figure 5-1. Map Showing the Location of Alternative Fuel Transit Bus Fleets



natural gas buses. Data are being collected from Metropolitan Suburban Bus Authority in Nassau County, Niagara Frontier Transit Authority in Buffalo, Central New York Transit Authority in Syracuse, Rochester-Genesee Regional Transit Authority in Rochester, and Broome County. The Metropolitan Suburban Bus Authority is the only transit property that has an onsite fast-fill refueling facility. Niagara Frontier Transit Authority currently has a time-fill refueling facility set up to refuel their buses. This facility is "bare-bones" and does not have the capability to measure the amount of natural gas delivered to each bus. Central New York Transit Authority, Rochester-Genesee Regional Transit Authority, and Broome County all have arrangements with their local utilities to refuel their buses at nearby utility compressed natural gas refueling facilities.

The fuel economy of a transit bus is dependent on a variety of factors including engine efficiency, the weight of the bus, and typical routes that the bus travels. Idle time is especially important because the fuel consumed during idle does no useful work to move the vehicle. The rate of fuel consumption at idle is one of the larger differences in engine efficiency between typical diesel transit bus engines and the Cummins L10 natural gas engine. Spark-ignition engines typically have about four times the fuel consumption, on an equal energy basis at idle, compared to diesel engines of similar size.

For transit buses, fuel economy is expressed in miles per gallon of diesel fuel. Natural gas is measured in units of standard cubic feet (SCF) or therms (100,000 Btus). To properly compare the fuel economy of the compressed natural gas buses to their diesel counterparts, it is necessary to calculate fuel economy in miles per diesel gallon equivalent, using the heating content of both the natural gas and the diesel fuel. Shown in Table 5-2 is the variation in standard cubic feet of natural gas that equals one gallon of diesel fuel at each transit property.

Table 5-2. Equivalence Between Natural Gas and Diesel Fuel

	Central New York Transit Authority	Rochester-Genesee Regional Transit Authority	Metropolitan Suburban Bus Authority	Broome Co.
SCF of natural gas per diesel gallon equivalent	134	126	129	133

The fuel economies for the compressed natural gas and diesel buses are presented in Table 5-3. Efforts were made to choose buses that used the same routes and traveled similar distances each day. The data of Table 5-3 suggest that this criteria was met fairly well.

Table 5-4 compares fuel economies. Amounts less than 1 indicate that the fuel economy of the compressed natural gas buses is less than their diesel counterparts, whereas numbers greater than 1 indicate better fuel economy. As illustrated in Table 5-4, Rochester-Genesee Regional Transit Authority stands out from the others with much better relative fuel economy. Conversations with Rochester-Genesee Regional Transit Authority personnel suggest that this may be because they used express-type routes with very little idle time and a relatively high average speed. Given these conditions, it would be expected that there would be small differences in fuel economy because at high loads the differences in thermal efficiency between the natural gas and diesel engines is at their minimum whereas at idle the differences are at a maximum.

The difference between the CNG1 and CNG2 groups of buses at Metropolitan Suburban Bus Authority bears some mention. Before emissions testing could be initiated, Metropolitan Suburban Bus Authority changed the engine management system on five of their ten compressed natural gas buses to give these buses more torque (850 ft-lbs versus 750 ft-lbs) and lower oxides of nitrogen (NO_x) emissions. In addition to engine management software changes, the CNG2 buses also had a Tescom single type high pressure regulator replace the dual type high pressure regulators. In the table, these buses are designated as "CNG2" with the compressed natural gas buses in original configuration listed as "CNG1". One of the CNG1 group of buses could not be tested because of transmission problems during

Table 5-3. Fuel Economy for Compressed Natural Gas and Diesel Buses

Transit Property	Miles Per Gallon (Diesel Gallon Equivalent)	Miles Per Day
Central New York Transit Authority CNG	2.91	128
Central New York Transit Authority DIESEL	4.15	116
Rochester-Genesee Regional Transit Authority CNG	3.48	163
Rochester-Genesee Regional Transit Authority DIESEL	3.54	149
Metropolitan Suburban Bus Authority CNG1	2.88	141
Metropolitan Suburban Bus Authority CNG2	2.79	138
Metropolitan Suburban Bus Authority DIESEL	3.71	171
Broome Co. CNG	3.26	147
Broome Co. DIESEL	3.99	155

Table 5-4. Fuel-Economy Differences by Transit Property

	Central New York Transit Authority	Rochester-Genesee Regional Transit Authority	Metropolitan Suburban Bus Authority CNG1	Metropolitan Suburban Bus Authority CNG2	Broome Co.
Ratio of CNG to Diesel MPG	0.70	0.98	0.78	0.75	0.82

the emissions test period. The decrease in fuel economy for the CNG2 is expected given that the calibration is likely richer than before (substantiated by the emissions test results) and the fact that more power is available to the driver. The Metropolitan Suburban Bus Authority fuel-economy results may be lower than the other transit properties because they travel significantly fewer miles per day than their diesel counterparts.

The emissions testing was conducted during August of 1993. Emissions were measured at the New York City Department of Environmental Protection Agency Frost Street Vehicle Emission Test Laboratory. Because of the distance between the transit bus project location and the emissions laboratory, it was only practical to measure emissions from the Metropolitan Suburban Bus Authority Buses. Engine configuration and bus weight are major variables that affect bus emissions. The other compressed natural gas buses that use the same transmissions are likely to have very similar emissions over the same driving cycles.

Table 5-5 lists the buses tested and their accumulated mileage at the time of testing. The Cummins L10 engines in the compressed natural gas buses are operated "lean," meaning that more air is admitted into the combustion chamber than is theoretically needed to complete combustion. Lean-burn engines tend to have very low carbon monoxide (CO) emissions, low oxides of nitrogen (NO_x) emissions, and high hydrocarbon emissions. Methane, the primary constituent of natural gas, is the most stable of all the hydrocarbons and resists oxidation at low temperatures. In-cylinder temperatures in lean-burn systems are relatively low due to the diluent effect of the excess air. To counteract this characteristic of lean-burn engines, Cummins has added an oxidation catalyst to this engine which lowers hydrocarbon emissions somewhat, but it is not as effective as for other fuels because methane is difficult to oxidize at the relatively low exhaust temperatures.

Two diesel buses were emissions-tested as a baseline to allow comparison with the emissions performance of many existing buses in transit property fleets. The two diesel control buses were 1991-model-year Orion 40-foot transit buses with DDC 6V-92TA engines and Allison 4-speed automatic transmissions. Emissions data from four New York City 1990-model-year TMC 40-foot transit buses with DDC 6V-92TA engines with Donaldson particulate traps were included for comparison purposes even though particulate trap technology may not be a choice for transit bus emission control in the future. The emissions tests consist of operating the buses on a chassis dynamometer over a prescribed driving cycle. The driving cycle used for emissions testing was the Central Business District transit-bus test cycle.

Figure 5-2 illustrates the differences in hydrocarbon emissions among these groups of buses. The CNG1 buses have similar total hydrocarbon emissions as the baseline diesel buses, but the vast majority of these hydrocarbons are methane which, although relatively non-reactive, is a significant greenhouse gas. The CNG2 buses show a large increase in hydrocarbon emissions. In lean-burn engines such as these, lowering oxides of nitrogen (NO_x) emissions often has an opposite effect on hydrocarbon emissions. The trap buses tended to have hydrocarbon emissions slightly less than the diesel baseline buses. This could be due to the fact that traps, in addition to collecting particulate matter, tend to cause a small amount of hydrocarbon oxidation to occur.

Table 5-5. Compressed Natural Gas Test and Diesel Fuel Baseline Buses

Bus No.	Group	Engine	Transmission	Miles
657	CNG1	Cummins L10	ZF	6,649
658	CNG1	Cummins L10	ZF	16,962
660	CNG1	Cummins L10	ZF	16,976
666	CNG1	Cummins L10	ZF	14,624
661	CNG2	Cummins L10	ZF	15,298
662	CNG2	Cummins L10	ZF	17,659
663	CNG2	Cummins L10	ZF	16,789
664	CNG2	Cummins L10	ZF	13,869
665	CNG2	Cummins L10	ZF	17,036
624	Baseline	DDC 6V-92TA	Allison	102,256
615	Baseline	DDC 6V-92TA	Allison	101,384
8005	TMC Trap	DDC 6V-92TA	ND[1]	48
8350	TMC Trap	DDC 6V-92TA	ND	16,132
8015	TMC Trap	DDC 6V-92TA	ND	41,236
8223	TMC Trap	DDC 6V-92TA	ND	74

[1] Not Determined.

Figure 5-2. Comparison of Unburned Hydrocarbon Emissions
from Compressed Natural Gas and Diesel Buses

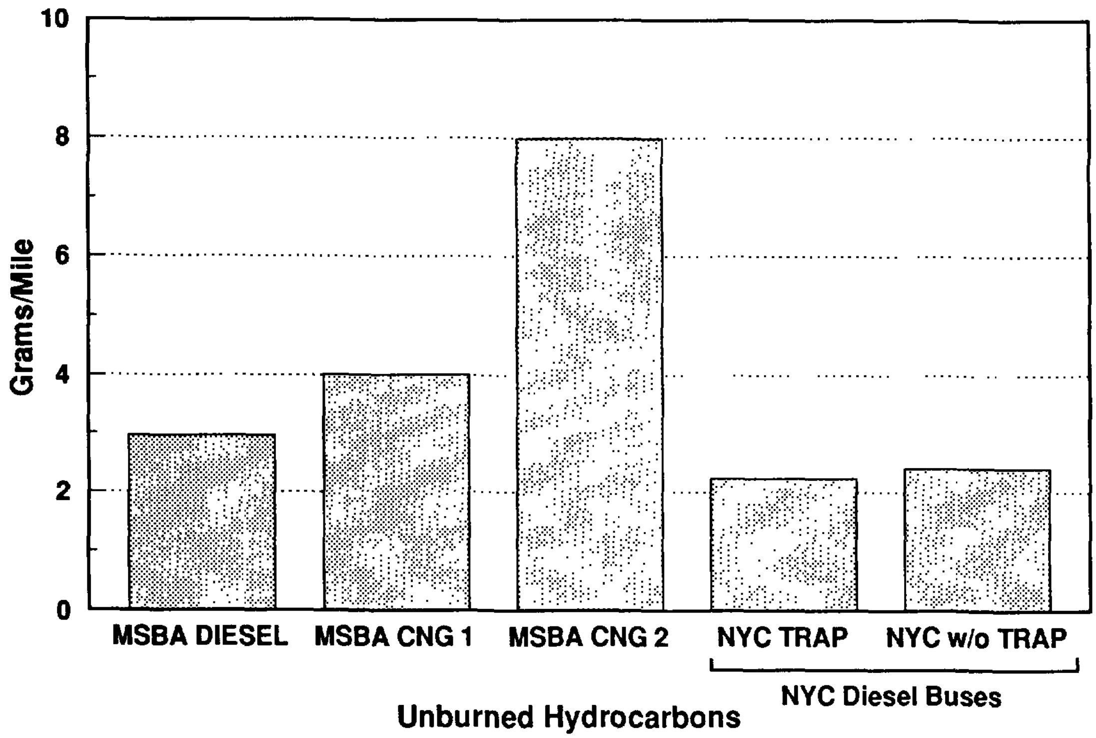


Figure 5-3 illustrates the differences in carbon monoxide (CO) emissions among these groups of buses. Both CNG1 and CNG2 buses have very low carbon monoxide (CO) emissions, which is a characteristic of lean-burn engines equipped with catalysts. The trap buses have significantly higher carbon monoxide (CO) emissions than the baseline diesel buses. This could be due to the fact that hydrocarbons oxidized in the particulate trap create carbon monoxide (CO) emissions which add to those produced by the engine. This supposition is supported by the data of Figure 5-3 that illustrate higher carbon monoxide (CO) emissions for the trap buses when using the traps.

Figure 5-4 illustrates the differences in oxides of nitrogen (NO_x) emissions among these groups of buses. As expected, the CNG2 buses' nitrogen (NO_x) emissions are nearly half those of the CNG1 buses, which are in turn only about 75 percent of the baseline diesel fuel oxides of nitrogen (NO_x) emissions. As expected, traps have insignificant impact on oxides of nitrogen (NO_x) emissions.

Figure 5-3. Comparison of Carbon Monoxide (CO) Emissions from Compressed Natural Gas and Diesel Buses

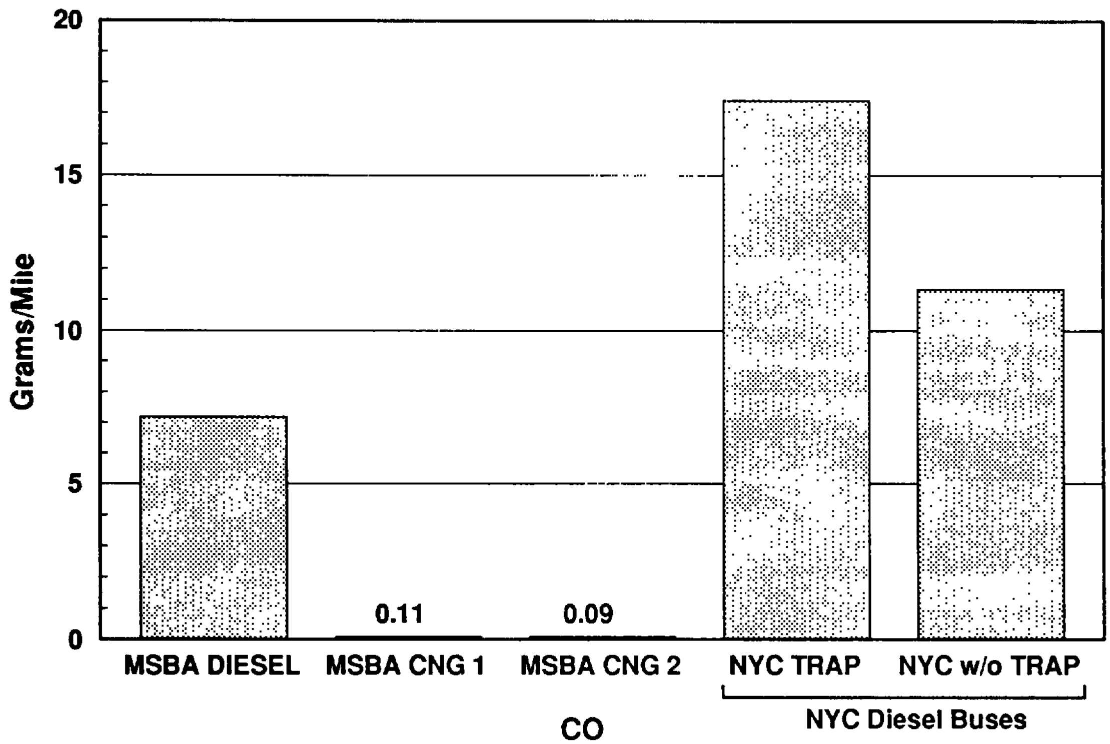


Figure 5-5 illustrates the differences in particulates among these groups of buses. The compressed natural gas buses show more than 95 percent reduction in particulates compared to the baseline diesel buses. Natural gas does not produce fuel-derived particulate emissions because the air-fuel ratio is high (lean) and the air and fuel are well mixed prior to combustion. The small amount of particulates emitted when using natural gas are from lubricating oil consumed in the engine. Figure 5-5 also illustrates that the particulate traps are about 80 percent efficient.

5.1.2.2 Liquified Natural Gas and Compressed Natural Gas Buses

Compressed natural gas and liquefied natural gas buses differ only in their fuel storage/dispensing systems. There are a number of different engine fuel systems that can be used with both compressed natural gas and liquified natural gas. All of the compressed natural gas buses that were discussed in the preceding section were equipped with spark-ignition engines. Several of the liquified natural gas buses used in the Houston Metropolitan Transit Authority demonstration project are pilot-injection natural gas (PING) engines that were supplied by Detroit Diesel Corporation. Several of the pilot-injection

Figure 5-4. Comparison of Oxides of Nitrogen (NO_x) Emissions from Compressed Natural Gas and Diesel Buses

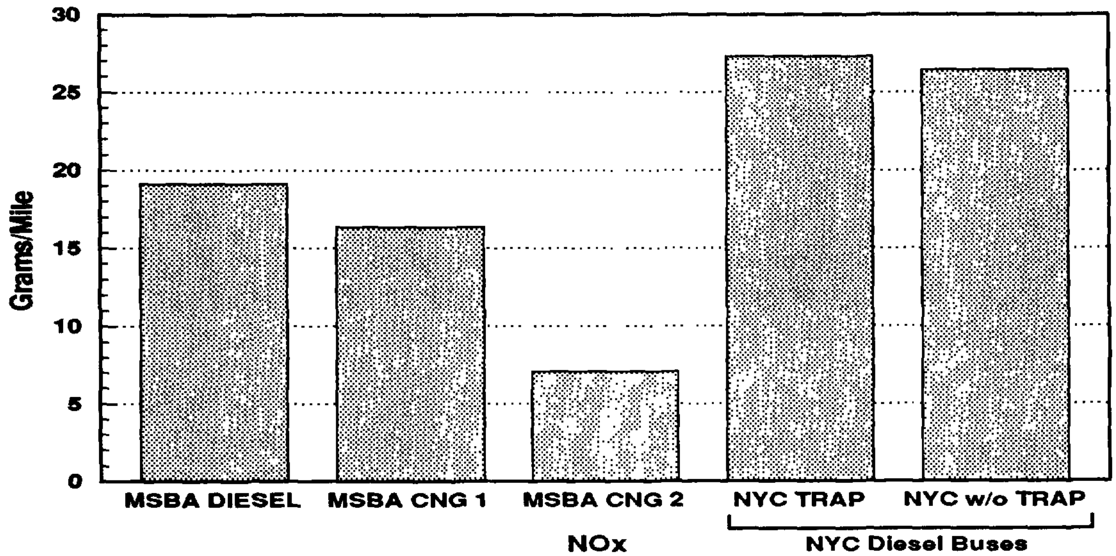
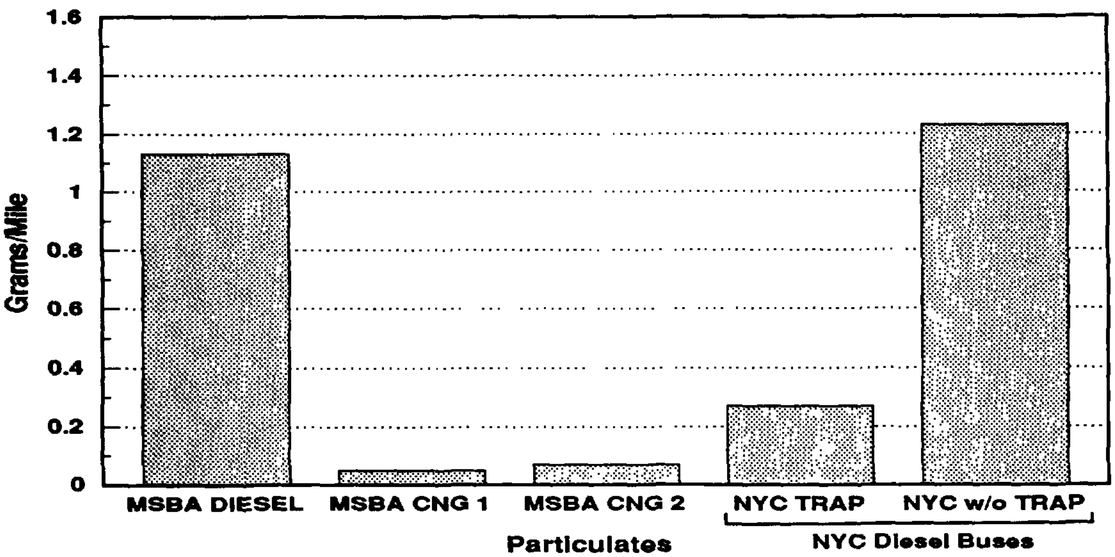


Figure 5-5. Comparison of Particulate Emissions from Compressed Natural Gas and Diesel Buses



natural gas engines were emissions-tested using the West Virginia Transportable Emissions Laboratory.

Shown in Figure 5-6 are the emissions of carbon monoxide (CO), oxides of nitrogen (NO_x), and hydrocarbon for six similar buses with diesel/liquified natural gas, diesel/compressed natural gas, clean diesel/liquified natural gas, and clean diesel/compressed natural gas pilot-injection natural gas engines, as well as diesel and clean-diesel control buses. The carbon monoxide (CO) emissions for the pilot-injection natural gas engines are significantly higher than those for the diesel control vehicles. Oxides of nitrogen (NO_x) emissions are fairly consistent across the range of engines. The higher oxides of nitrogen (NO_x) emissions for the diesel/compressed natural gas engine and the lower oxides of nitrogen (NO_x) emissions for the diesel/liquified natural gas system are probably due to a difference in the engine calibrations rather than any fundamental difference in liquified natural gas versus compressed natural gas fuels. As would be expected, the pilot-injection natural gas engines exhibit extremely high total hydrocarbon emissions.

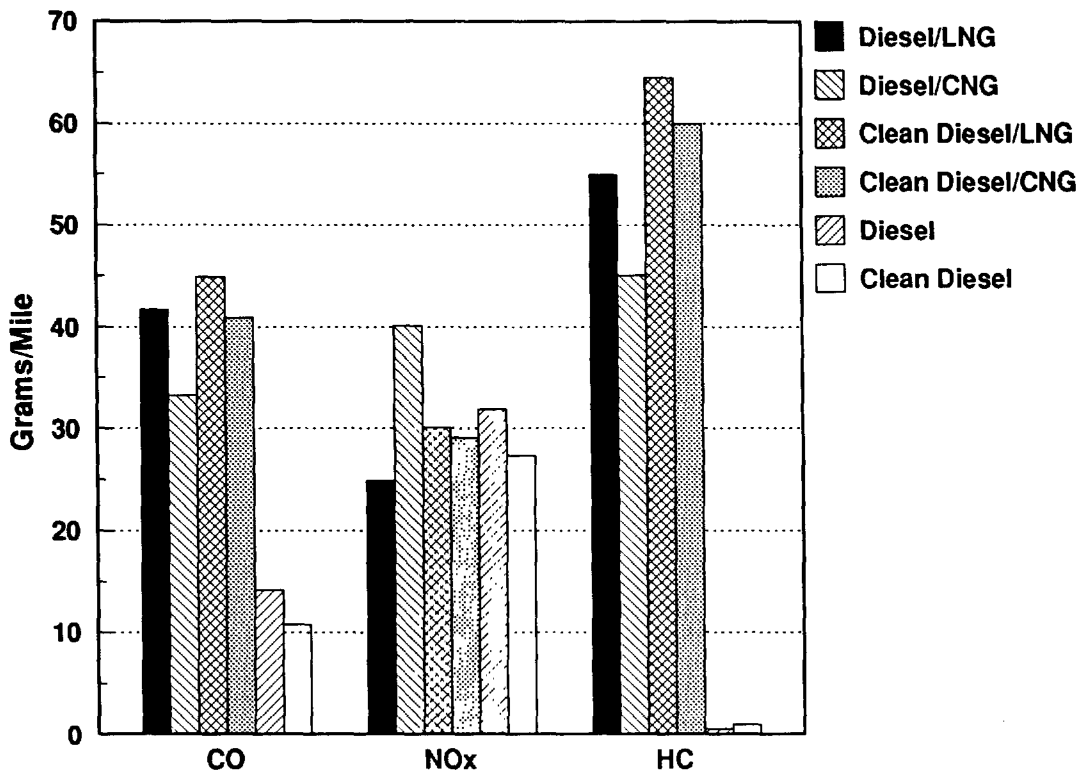
The spark-ignition natural gas engines discussed in the preceding sections had fairly low hydrocarbon emissions because of their catalytic converters. However, none of the pilot-injection natural gas engines discussed here were equipped with catalytic converters. Because of the high hydrocarbon emissions for this type of engine, Detroit Diesel Corporation is concentrating its efforts on the development of spark-ignition natural gas engines rather than continuing the development of the pilot-injection natural gas engine. Even though the hydrocarbon emissions for the pilot-injection natural gas engines are largely composed of methane, this level of hydrocarbon emissions would probably be unacceptable for commercial applications in the long term.

Another concept for a pilot-injection natural gas engine is known as fumigation and is largely supplied by aftermarket providers. In these systems, natural gas is introduced into the intake air stream of a four-stroke cycle diesel engine and premixed with air in the intake manifold and during the compression stroke. Near the end of the compression stroke, a small amount of diesel fuel is, injected which compression ignites, and provides a flame for igniting the premixed charge of natural gas and air.

Fumigation systems typically exhibit extremely high hydrocarbon emissions. Moreover, the aftermarket systems show a much wider range of hydrocarbon emissions than the pilot-injection natural gas system. This may be because most aftermarket providers do not have the required instrumentation to properly evaluate and calibrate the systems when they are installed.

Shown in Figure 5-7 are particulate emissions and fuel economy as determined during the emissions testing. It is interesting to note that particulate emissions for the pilot-injection natural gas engines are nearly the same as those for the diesel control vehicles, even though the majority of the fuel consumed during the driving cycle is natural gas. Part of these particulate emissions are accounted for by lubricating oil consumption, but in this case there appears to be a large contribution from the pilot injection, and/or incomplete mixing of the natural gas with air during the compression stroke.

Figure 5-6. Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), and Hydrocarbon Emission for Pilot Injection CNG and LNG Buses Compared to Diesel Control Buses



The fuel economy of the six buses tested is comparable, with the exception of the two diesel/compressed natural gas buses. There is no information available which would provide an explanation for this difference in fuel economy.

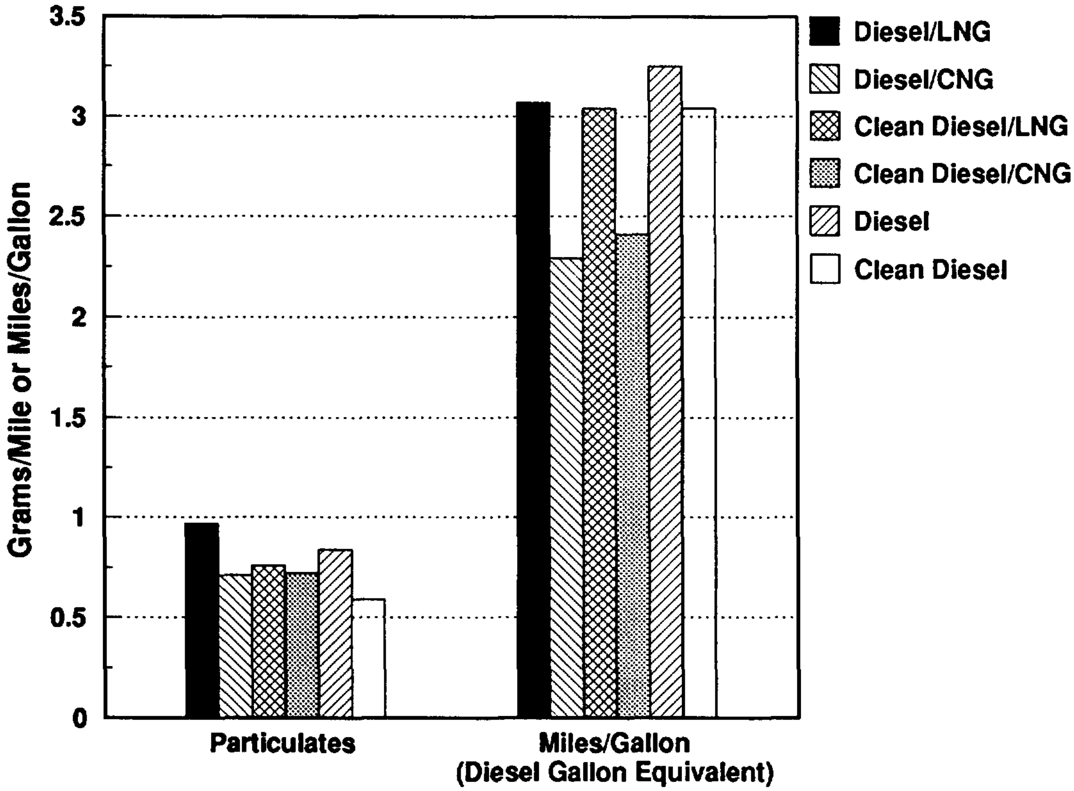
5.1.2.3 Methanol Buses

A number of transit bus projects around the United States are evaluating methanol as an alternative fuel for transit bus applications. The Riverside Transit Agency, Riverside, California, a representative example, is currently operating three methanol buses and three diesel control buses in an alternative fuels demonstration project.

Both the methanol buses and the diesel control buses in the demonstration are equipped with DDC 6V-92 engines. The methanol engines are operated on 100 percent methanol and the diesel engines are operated on No. 2 diesel fuel.

Shown in Table 5-6 are data for the three methanol buses and the three diesel control vehicles over the life of the project to date.

Figure 5-7. Particulate Emission and Fuel Economy for Pilot Injection Compressed Natural Gas and Liquefied Natural Gas Buses Compared to Diesel Control Buses



Over the life of the bus, the cost per mile of the methanol buses is more than twice that of the diesel buses. The most significant difference in costs are related to labor, repair parts, and higher cost of the methanol fuel. There is an increased number of road calls for the methanol buses. However, in spite of the increased road calls, the uptime of methanol buses was still greater than 90 percent. (It should be noted that road calls are for all reasons, not just engine/fuel system problems.) Higher costs for operating the methanol buses are to be expected because methanol engine development is still in progress. As these engines become more developed, their reliability will increase, and the life-cycle cost will decrease. One must remember that diesel buses have been in service for more than 30 years, and the technology is mature in terms of reliability and durability.

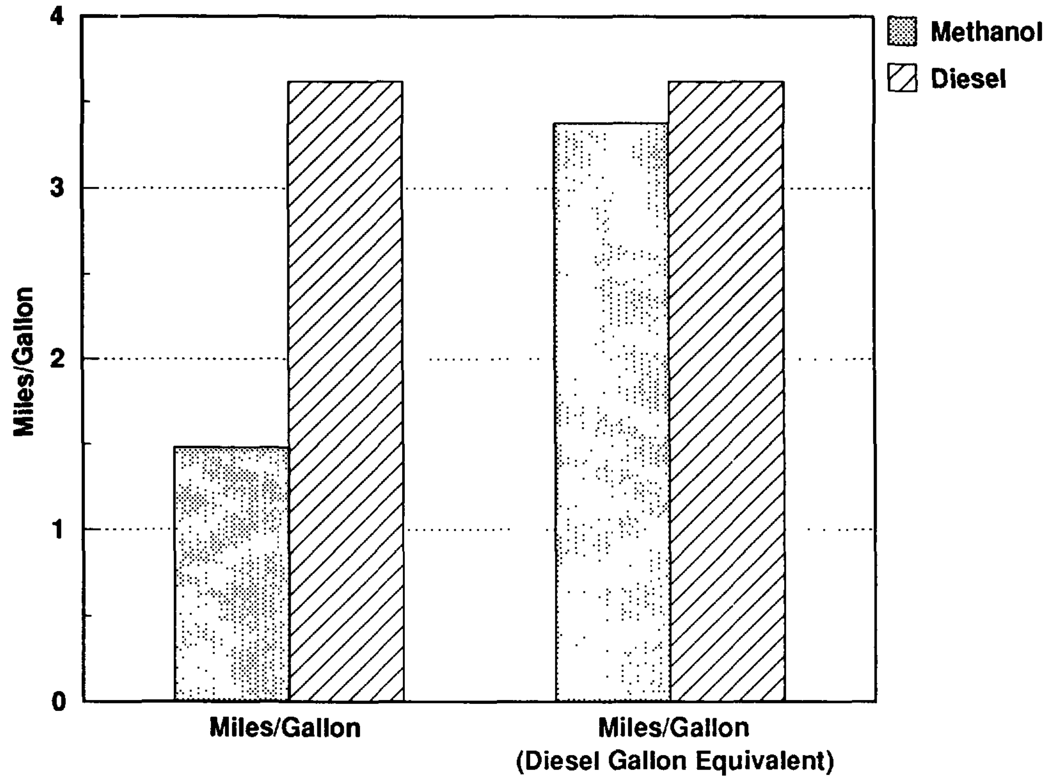
On-road fuel economy for three methanol and three diesel control buses is depicted in Figure 5-8. When methanol fuel economy is expressed in terms of diesel gallon equivalent miles per gallon, the methanol fuel economy is less than that for the diesel vehicles. When the methanol engine technology matures, the fuel economy for both methanol and diesel buses should become nearly equal.

Table 5-6. On-Road Operational and Cost Data for Three Methanol and Three Diesel Buses in the Riverside Transit Bus Demonstration Project

	Methanol	Diesel
Total Miles	261,707	446,784
Fuel Economy, Miles/Gallon (Diesel Gallon Equivalent Miles/Gallon)	1.48 (3.38)	3.62
Oil Economy, Miles/Quart	420	389
Number of Road Calls	35	7
Total Labor Hours	651	120
% of Uptime	91.2	99.3
Labor Costs	$10,482.34	$1,916.11
Parts Cost	$41,003.74	$10,871.17
Fuel Cost	$98,112.70	$79,916.11
Total Cost	$149,598.78	$92,704.08
Cost Per Mile	$0.57	$0.21

During November of 1992, one of the methanol buses and one of the diesel buses from the Riverside project were tested for emissions by the West Virginia Transportable Emissions Laboratory. The driving cycle used for these emissions test was the central business district transit-bus cycle. The emissions of carbon monoxide (CO) and oxides of nitrogen (NO_x) from the two test vehicles are shown in Figure 5-9. In this case, the methanol bus gave lower carbon monoxide (CO) emissions than the diesel bus. (Carbon monoxide (CO) emissions can vary over a wide range depending on the driving cycle and from engine-to-engine. Research has shown that some methanol engines produce more carbon

Figure 5-8. On-Road Fuel Economy of Methanol and Diesel Control Buses



monoxide (CO) emissions than others, and their emissions are not always lower than those for corresponding diesel engines.) The oxides of nitrogen (NO_x) emissions are generally more predictable and consistent from engine-to-engine and from test-to-test when compared to carbon monoxide (CO) emissions. Figure 5-9 shows the classic result that methanol produces lower oxides of nitrogen (NO_x) emissions than does diesel fuel. This is primarily due to the higher latent heat of vaporization of methanol. The lower oxides of nitrogen (NO_x) for methanol results from the cooling effect when methanol is injected into the combustion chamber, with the final result effectively reducing the temperature of combustion, which favors lower oxides of nitrogen (NO_x) production.

Illustrated in Figure 5-10 are the organic and particulate emissions compared between the methanol and diesel control buses. Unburned methanol and formaldehyde were not measured for the diesel bus. It is known from past research studies that formaldehyde and methanol emissions from diesel engines are low when compared to methanol engines. The organic material hydrocarbon equivalent is determined by summing the masses of residual hydrocarbon, adjusting for values of methanol and formaldehyde. This has the result of subtracting out the oxygen portion of these emissions and making the value comparable on a mass basis to the hydrocarbon emissions measured from diesel engines. For the methanol bus

Figure 5-9. Carbon Monoxide (CO) and Oxides of Nitrogen (NO_x) Emissions from Methanol and Diesel Control Buses

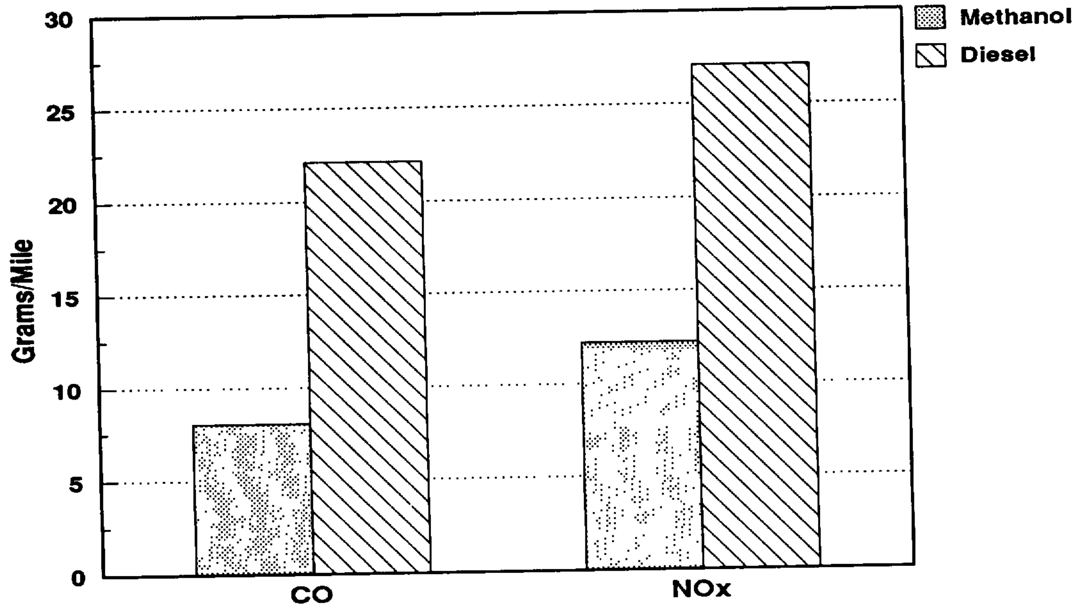
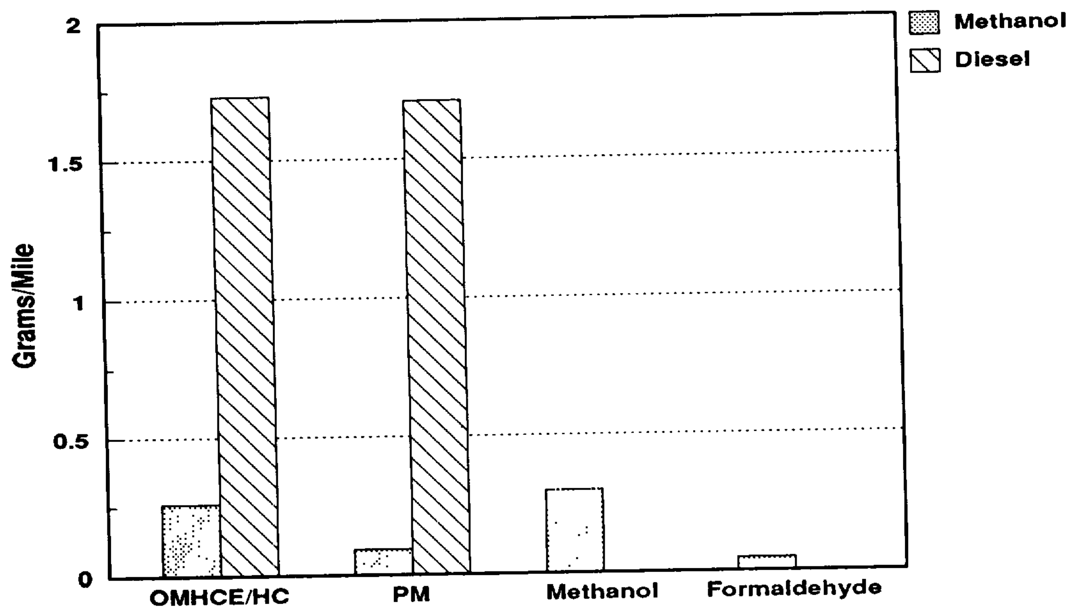


Figure 5-10. Organic and Particulate Emission from Methanol and Diesel Control Vehicles



tested, the organic material hydrocarbon equivalent emissions were significantly lower than the hydrocarbon emissions from the diesel control bus.

The particulate emissions from the methanol bus were also significantly lower than those for the diesel bus. The small amount of particulate emissions for the methanol bus is probably derived from lubricating oil that is consumed by the engine. Oil consumption for the methanol bus (Table 5-5) was slightly lower than that for the diesel control bus. As the design of methanol engines improve, oil consumption should be reduced with a corresponding reduction in exhaust particulates. In summary, it appears that catalytic converters may be required to control unburned methanol and aldehydes for methanol fueled buses. These exhaust emission components are easily converted in catalytic converter systems.

The fuel economy associated with the emissions testing is determined by a carbon-balance method, which is common practice in automobile emissions testing. The fuel economy for the two buses for the emissions tests shown in Figure 5-11 shows a different result from that discussed earlier for the on-road data. In this case, the diesel gallon equivalent fuel economy of the methanol bus was greater than that for the diesel control bus, which is the opposite of that measured in the on-road tests. In the emission testing, the driving cycle is fixed and both buses are forced to follow the same driving schedule of vehicle speed versus time, and accelerations. In case of the on-road tests, the driving cycle can vary depending on the bus route, the driver, vehicle acceleration performance, and other factors. Therefore, it is not unusual for one bus to show better fuel economy than another bus in one case, whereas the reverse trend might be shown on a different driving schedule.

5.1.2.4 Ethanol Buses

The Greater Peoria Mass Transit District in Peoria, Illinois, is operating several ethanol transit buses. The emissions and fuel economy characteristics of these buses were determined by West Virginia University using the Transportable Emissions Testing Laboratory. Emissions tests were conducted on five ethanol buses and two diesel control buses. The ethanol buses were equipped with DDC 6V-92 engines that were derived from the DDC methanol engine which has been commercialized for bus applications. The fuel for the ethanol engines was E95. The diesel control buses were equipped with DDC 6V-92 production diesel engines. The fuel used in the bus engines was "Jet A" jet fuel, and the two diesel control vehicles were equipped with Donaldson particulate traps.

Shown in Figure 5-12 are the average carbon monoxide (CO), oxides of nitrogen (NO_x), and organic material hydrocarbon equivalent/hydrocarbon emissions from the ethanol and diesel control buses. Carbon monoxide (CO) emissions were somewhat lower for the ethanol buses than for the diesel control buses. This trend is consistent with that of the Riverside Transit Agency's methanol buses. The lower oxides of nitrogen (NO_x) emissions for the ethanol buses is consistent with classic results that show that ethanol fuel produces lower oxides of nitrogen (NO_x) emissions than diesel fuels, due to the relatively higher latent heat of vaporization of ethanol as compared to diesel or jet fuel. On the other hand, the organic material hydrocarbon equivalent emissions for the ethanol buses are substantially higher than the hydrocarbon emissions for the diesel control buses.

Figure 5-11. Fuel Economy for Methanol and Diesel Control Vehicles During the Emissions Test Cycle

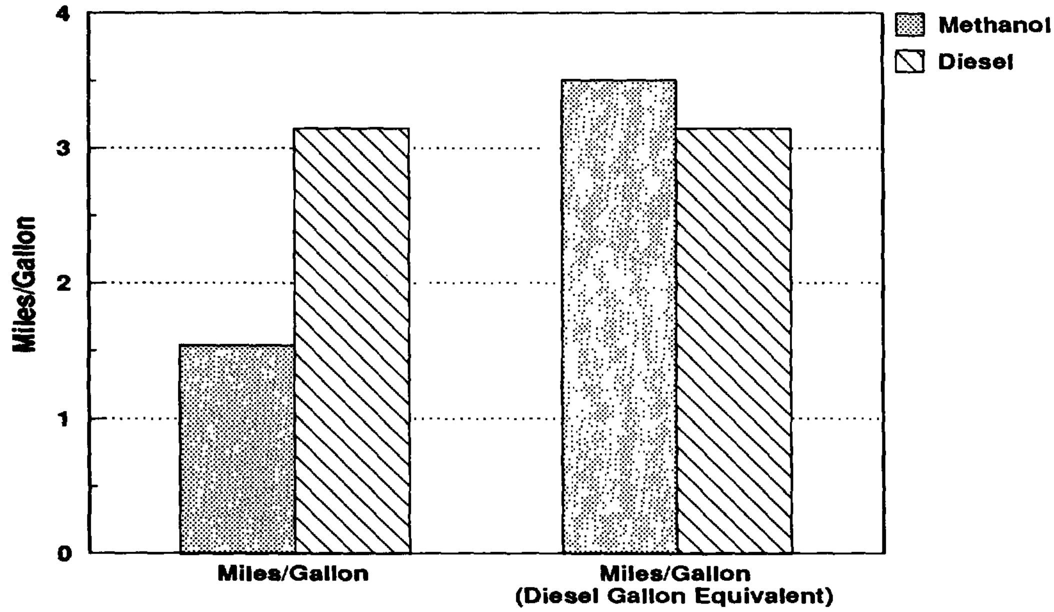
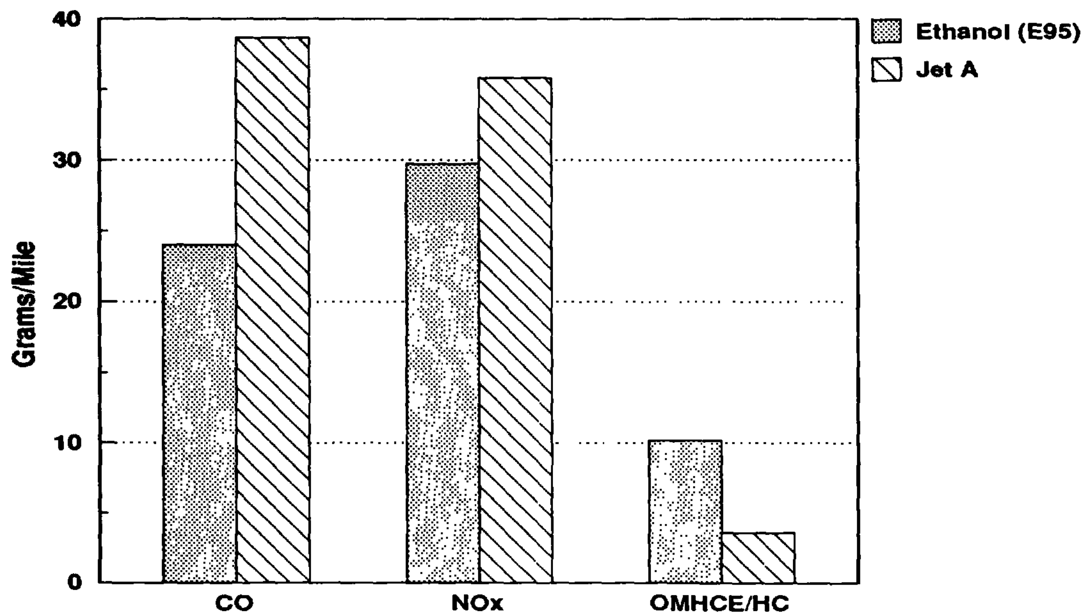
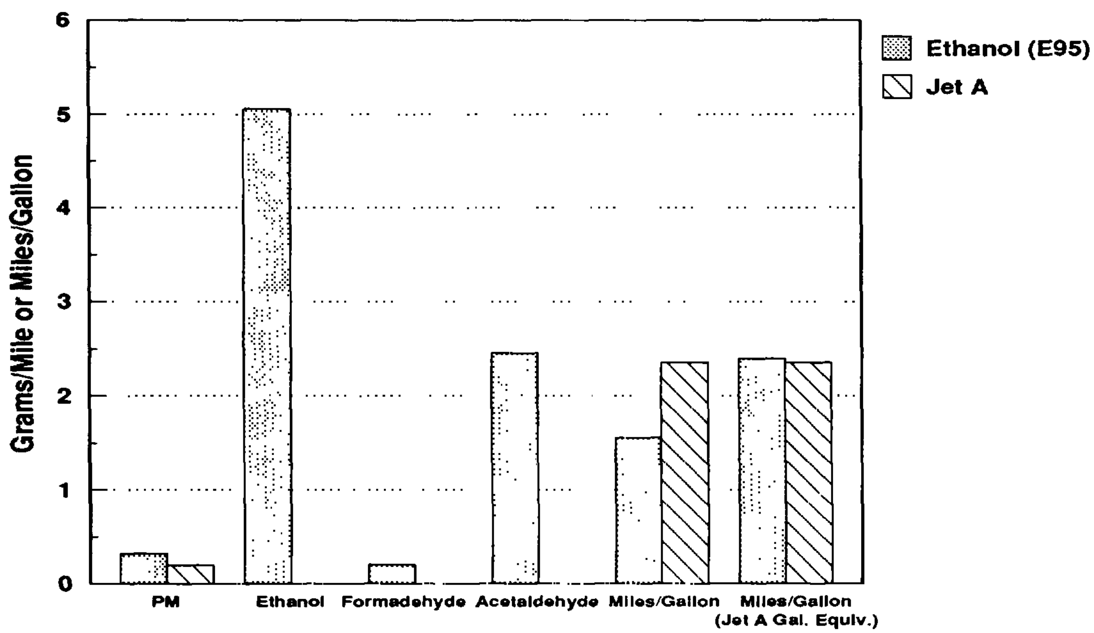


Figure 5-12. CO, NO_x, and Organic Material Hydrocarbon Equivalent/ Hydrocarbon Emissions from the Ethanol and Diesel Buses



Shown in Figure 5-13 are the particulate, other organic emissions, and fuel economy as determined during the emissions testing procedures. The results show that the particulate emissions from the ethanol buses were slightly higher than those from the diesel control vehicles. The primary reason for the low particulate emissions from the diesel control buses is that they were equipped with particulate traps. As mentioned earlier, lubricating oil consumption can contribute to particulate emissions. No data are available at the present time to assess the oil consumption of the ethanol buses.

Figure 5-13. Particulate, Unburned Ethanol, Aldehyde Emissions, and Fuel Economy for the Ethanol and Diesel Buses



The ethanol and aldehyde emissions from the ethanol engines were quite high, as would be expected, because these vehicles were not equipped with catalytic converters. Aldehyde emissions data were not collected for the diesel control buses. The fuel economy for the ethanol buses was comparable to the diesel control buses when adjusted for the differences in heating values between the two fuels.

In summary, the ethanol buses appear to be performing similarly to the diesel control vehicles, with the exception of unburned ethanol and aldehydes. Most of the unburned ethanol and aldehydes can be eliminated with the use of catalytic converter systems. It appears that all of the alternative fuel engines will require some kind of exhaust after-treatment to meet future clean-air requirements.

5.2 Future Transit Bus Activities

The initial phase of the Alternative Fuels Bus Program was structured to gain basic information from the existing bus demonstrations that are being managed by the U.S. Department of Transportation. For the future, a second-phase project has been designed by DOE to gather more-detailed data with limited numbers of alternative fuel buses from selected transit authorities. Data collection and analysis will continue on the current, as well as the new, projects.

5.3 School Bus Operations

In addition to the transit buses, DOE is coordinating, providing incentives, and assisting various school districts around the country in setting up alternative fuel demonstration vehicles.

5.3.1 Program Participants

In fiscal year 1992, the Department of Energy issued eleven grants as an initial phase to fund the incremental cost of alternative fuel school buses. This money was distributed in fiscal year 1993, with most of the school districts in the program receiving their money and ordering the buses. Many buses were acquired over the summer and had just begun operation at the end of fiscal year 1993. For this reason, only a limited amount of data is available. The results will be fully presented in the Fourth Annual Report to Congress.

Figure 5-14 shows the locations of the Phase I school buses. However, out of these eleven projects, only five buses started operation during fiscal year 1993. These buses were located in Wood County, West Virginia, and Shenendehowa Central School District, New York. The compressed natural gas buses in Wood County were emissions-tested over fiscal year 1993 and the results are presented in the following section. Figure 5-15 shows one of the Wood County CNG buses.

Unfortunately, with one exception, the compressed natural gas-powered school buses refueled at the Wood County, West Virginia, site did not have individual fuel-metering systems; therefore, on-road fuel economy figures can be calculated for only one bus. When the next generation of buses begins sustained operation, a larger amount of vehicles enter the data collection pool, and with the increased possibility of installing more fuel-metering devices, fuel economy figures will be calculated.

5.3.2 Vehicle Accumulated Miles

From December 1992 through September 1993, two buses in Wood County have accumulated 23,497 miles. Three additional buses went into service in July 1993 and these buses accumulated only 6,628 miles by September 1993. The total accumulation for these five buses is 30,125 miles as shown in Figure 5-16.

Figure 5-14. Locations of Current Phase I School Buses

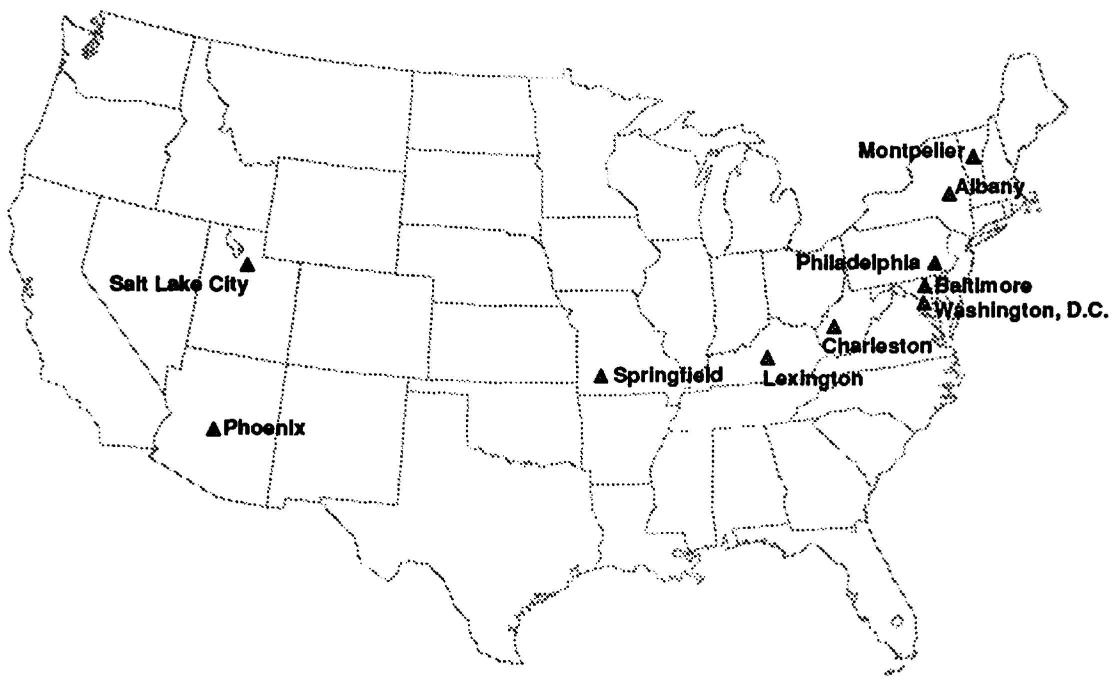
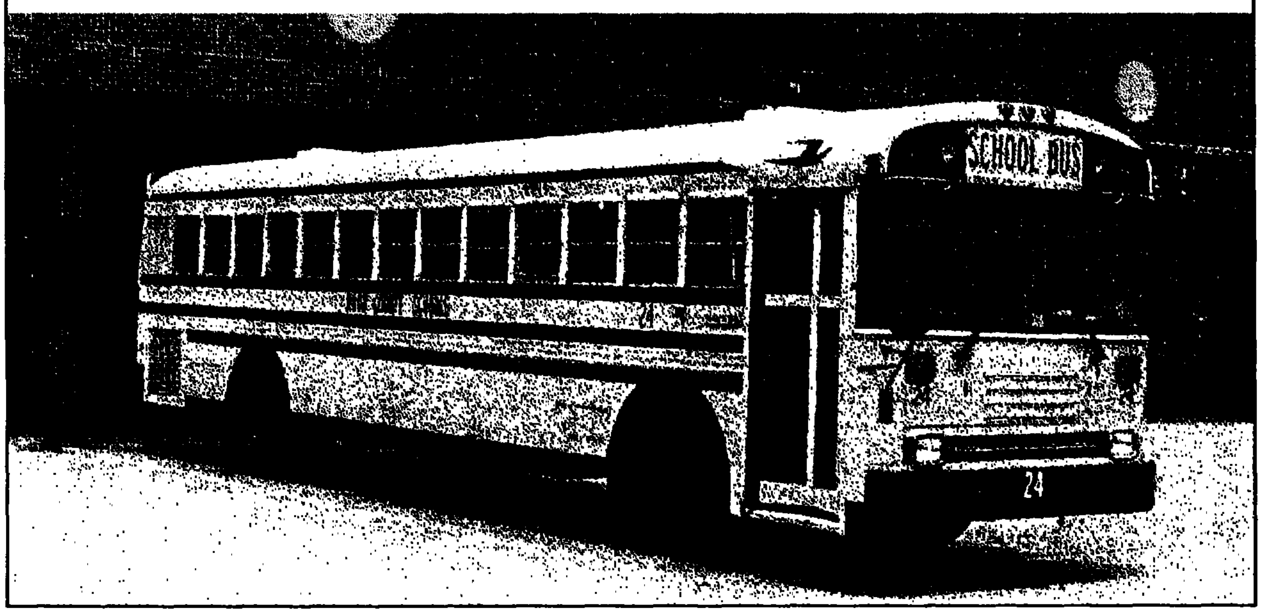


Figure 5-15. Wood County CNG Bus



5.3.3 School Bus Emissions

During calendar years 1992 and 1993, several school buses in the Wood County, West Virginia, School Bus Program were emissions-tested. The emissions tests were conducted by West Virginia University using the Transportable Emissions Testing Laboratory. The school buses that were tested included four compressed natural gas buses with Hercules natural gas engines and one bus with a Chevrolet gasoline engine converted to natural gas with an aftermarket conversion kit. Also included was a modified diesel engine with an aftermarket natural gas fumigation system along with gasoline and diesel control school buses.

As can be seen from Figure 5-17, carbon monoxide (CO) emissions vary over a wide range for the different fuel systems. The extremely high carbon monoxide (CO) emissions of 609 grams/mile for the converted gasoline engine is due to an over-rich air-fuel mixture. The low oxides of nitrogen (NO_x) emissions for the same engine is also indicative of an over-rich mixture. This illustrates the difficulty with many aftermarket natural gas conversion systems. If the proper equipment is not available to calibrate the engine air-fuel ratio when setting up the system, emissions can be extremely high. The carbon monoxide (CO) emissions from the Hercules natural gas engine and the fumigated engine are reasonable, but they are significantly higher than that for the diesel control vehicle. The carbon monoxide (CO) emissions for the gasoline control vehicle are not unusual for heavy-duty gasoline engines. Heavy-duty gasoline engines tend to have high carbon monoxide (CO) emissions because they are typically run rich at high loads to prevent the engine from failing due to high temperature during wide-open throttle accelerations and/or engine lugging during hill climbing.

The fumigated engine has high oxides of nitrogen (NO_x) emission and extremely high hydrocarbon emissions. The high hydrocarbon emissions are typical of this type of natural gas conversion system. The extremely high hydrocarbon emissions from this fumigated engine confirms the results of earlier research on natural gas engines that has been published in the technical literature over the years. It is also consistent with the results observed with similar systems that were discussed earlier in the transit bus section of this report.

Figure 5-18 shows particulate emissions from the several school buses that were tested. As would be expected, the compressed natural gas engines have markedly lower particulate emissions compared to the diesel control vehicle. The relatively high particulate emissions from the fumigated engine are primarily due to the diesel pilot fuel. The small amount of particulate emissions from the natural gas engines is due to the contribution of lubrication oil consumption to the formation of particulates in the combustion chamber.

Fuel economy for the different engines are reasonably comparable, with the exception of the converted gasoline engine and the gasoline engine. The relatively low fuel economy for these two engines is caused by the over-rich mixtures with correspond with wasted fuel in the form of carbon monoxide (CO) emissions that are emitted from the tailpipe.

In summary, the existing data indicate that significant engine development work is required on natural gas engines for natural gas to be a viable alternative fuel option for school

Figure 5-16. School Bus Mileage Accumulation

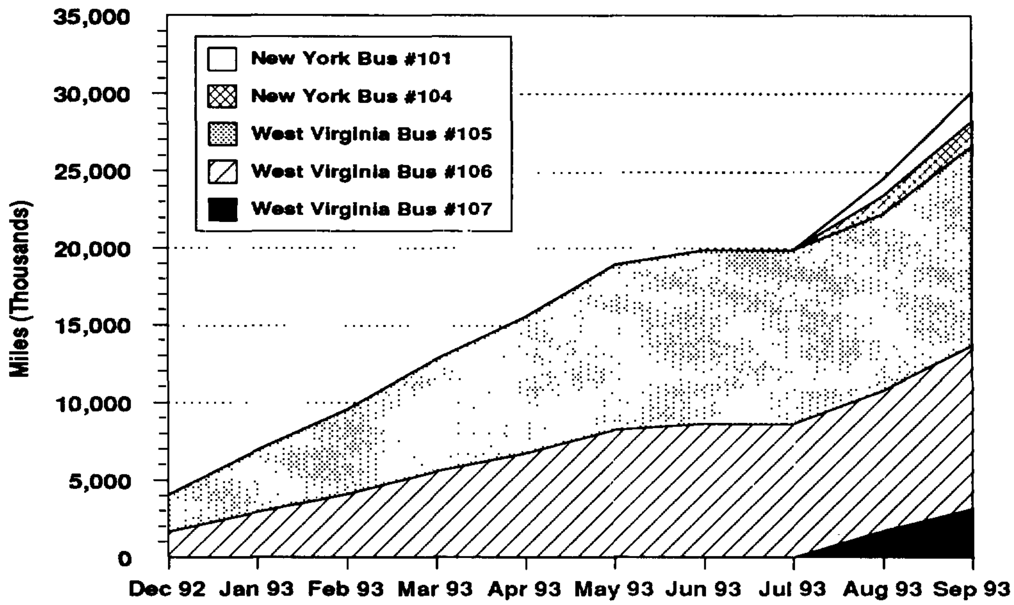


Figure 5-17. Gaseous Emissions for Alternative-Fueled School Buses Compared to Diesel and Gasoline Fuels

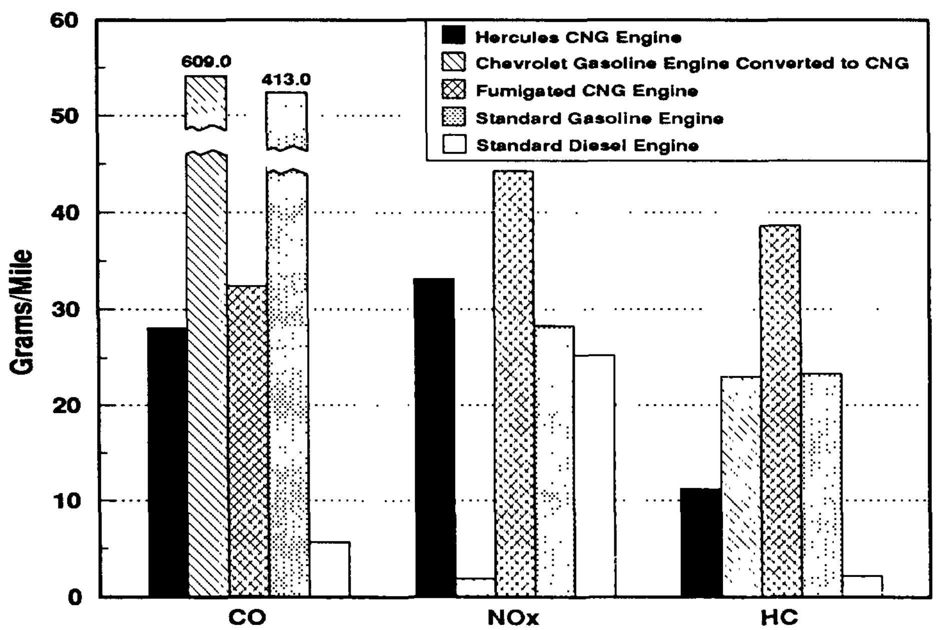
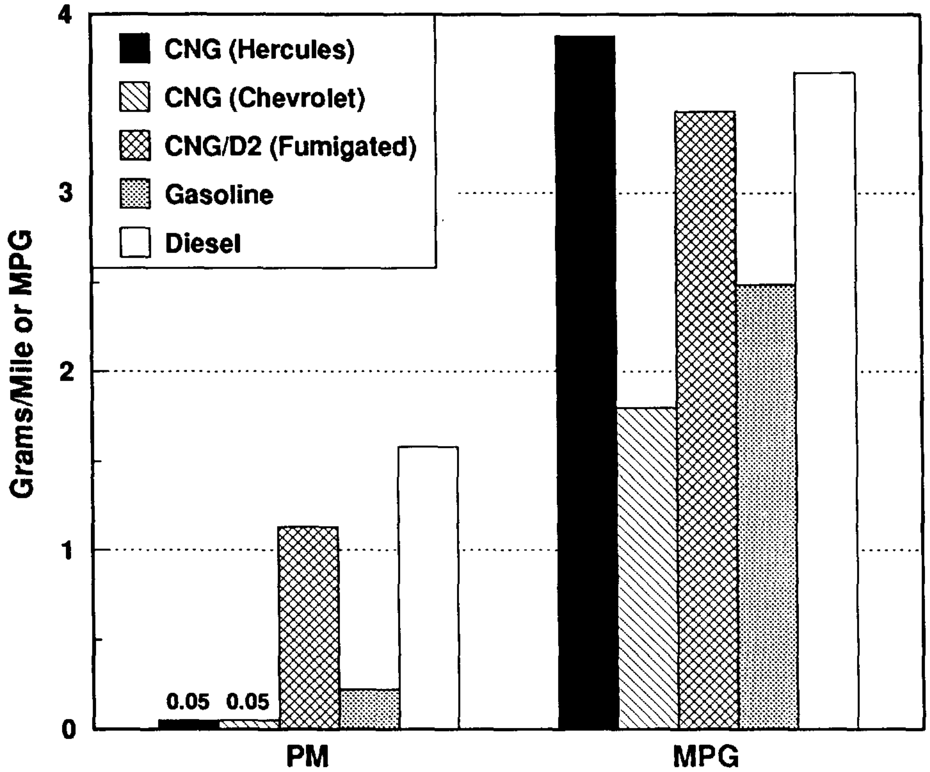


Figure 5-18. Particulate Emissions and Fuel Economy of School Buses Comparing Compressed Natural Gas with Diesel and Gasoline Engines



bus applications. It is expected that acceptable natural gas engines for school buses will emerge, but more engine development is required.

5.4 Future School Bus Activities

Currently, eleven localities have received grants for original equipment manufacturer alternative fuel school buses. Ten of these projects will be fueled with compressed natural gas and one will be fueled with methanol. At this point, only the Wood County, West Virginia, and Shenendehowa Central School District, New York, projects are operational and reporting data. The other nine locations will be operational in the near future. There are plans for a second phase of grants which would add another sixteen school bus project locations. Table 5-7 outlines the type, number, and location of these buses, along with anticipated delivery dates.

Table 5-7. School Bus - Heavy-Duty Delivery Schedule - Phase II Grants

Phase	State	Number of Vehicles	Type of Vehicles	Location	Scheduled for Delivery
II	Illinois	2	E95 Snow Plow/Construction trucks	Peoria, IL	To be determined
II	Illinois	1	E95 School Bus	Peoria, IL	To be determined
II	Kentucky	3	CNG Municipal Wreckers	Louisville/Jefferson County, KY	August 1994
II	North Carolina	4	CNG School Buses	Mecklenburg County, NC	To be determined
II	Nevada	2	CNG 15,000-GVW Crew Cab Dump Trucks	To be determined	March 1994
II	Nevada	2	CNG Tymco Street Sweepers	To be determined	March 1994
II	New York	2	CNG Athey Street Sweepers	New York City, NY	July 1994
II	New York	2	CNG Transit Style Buses used in school bus operation	Bethlehem School District, Albany County, NY	February 1994
II	Rhode Island	4	CNG School Buses	East Providence, RI	To be determined
II	South Carolina	4	CNG Heavy-Duty Trucks	Richland and Lexington Counties, SC	To be determined
II	Virginia	3	LPG Class 7 (28,000 - 33,000 GVW) Dump Trucks	Richmond, Northern Virginia, and Suffolk, VA	July 1994
II	Virginia	1	CNG School Bus	Virginia Beach, VA	October 1994

Table 5-7. School Bus - Heavy Duty Delivery Schedule - Phase II Grants (Cont.)

Phase	State	Number of Vehicles	Type of Vehicles	Location	Scheduled for Delivery
II	West Virginia	2	CNG Transit-Style Buses used in school bus operation	Pleasants County, WV	To be determined
II	District of Columbia	3	CNG Jet Vac Machines	Washington, D.C.	To be determined
II	District of Columbia	1	CNG 38,000-GVW Dump Truck	Washington, D.C.	To be determined
II	Iowa	4	Soy diesel (70% Soy diesel/30% Diesel blend) School Buses	Waco and Washington Community School Districts, IA	Delivered

6.0 SAFETY

The overall safety assessment of the vehicles in the Alternative Motor Fuels Program are based on information collected from communications with drivers involved in accidents, discussions with fleet managers, and queries of General Services Administration data on these vehicles. In addition, the National Highway Traffic Safety Administration maintains an automotive defects and recall data base and a special file on crashes involving alternative fuel and electric vehicles.

In response to the growing number of alternative fuel vehicles, the National Highway Traffic Safety Administration is in the process of developing safety standards that will regulate the safety performance of the fuel systems of these vehicles. During fiscal year 1993, the anti-siphoning performance of alcohol-fueled vehicles of 4,536 kilograms gross-vehicle-weight rating or less and all school buses was regulated (58 Fed. Reg. 5633).

The National Highway Traffic Safety Administration is also conducting rulemaking to develop safety standards for compressed natural gas fuel systems, and a final rule is scheduled to be promulgated in fiscal year 1994.

Examination of the National Highway Traffic Safety Administration manufacturer recall data base and discussion directly with vehicle manufacturers revealed the following safety-related recalls or no-cost warranty actions specifically targeted toward alternative fuel and electric vehicles:

- The 1992 Chevrolet Lumina with the methanol/ethanol fuel system was recalled for fuel leakage. These vehicles were returned to the dealers and the fuel tanks were replaced.

- The light-duty Phase II project M85 (a mixture of 85 percent methanol and 15 percent unleaded gasoline) Dodge Spirits were not allowed to go into service due to a leaking fuel sensor. These vehicles were returned to the dealers and the fuel sensors were replaced.

Analysis of the National Highway Traffic Safety Administration alternative fuel and electric vehicle crash file reveals only one vehicle collision in the September 1992 to September 1993 time period. This case (#DS 9202) involved an electric vehicle, which is not part of the current Alternative Motor Fuels Program.

On September 13, 1993, one Federal Express vehicle had a fire while operating on M85. The fire started under the hood and was quickly extinguished, with no injuries and minimal damage to the engine compartment wiring. Preliminary examination of the vehicle by Ford Motor Company indicated that the fire started near the cold-start injector, most likely from a fuel leak.

On December 6, 1992, a Neoplan transit bus powered by a dual-fuel Detroit Diesel 6V92 pilot-injection natural gas engine was damaged by a natural gas ignition. While new-vehicle inspection certification was being conducted at the Houston Metro Transit maintenance facility, a leak in the cryogenic fuel-pump system was discovered. Attempts were made to move the bus out of the shop to safely vent the leaking gas. A lack of communication with factory personnel resulted in the maintenance facility supervisor attempting to drive the vehicle out of the shop. Three attempts to start the vehicle were made, and on the last, the ignition occurred. Preliminary investigation suggests that the leaking natural gas collected in the air-conditioning return duct and was probably ignited by various relays operating in the vicinity. No injuries resulted from this incident.

Special Item

As this report was in final preparation, a significant event occurred. Two General Motors C2500 pickups running on natural gas, one in California and one in Minnesota, incurred identical compressed natural gas fuel tank ruptures, with injuries to personnel. Investigation into the cause of the fuel-tank ruptures is ongoing. However, preliminary results suggest that the tanks failed due to environmental degradation (most likely from contact with corrosive agents) of the outer composite wound reinforcement. Additional findings will be presented in future reports. Although these were not Federal vehicles, they were identical to 600 General Services Administration vehicles. The General Services Administration promptly issued orders to cease all operation of these vehicles. General Motors has recalled all of these vehicles (including the 600 Federal vehicles) and has agreed to refund the purchase price of these vehicles to the General Services Administration.

7.0 CONSUMER AWARENESS

In fiscal year 1993, various publications were prepared and distributed by the Department of Energy/National Renewable Energy Laboratory on the objectives of the Alternative Motor Fuels Program, current and planned demonstration projects, and technology facts about alternative fuels, such as compressed natural gas, liquefied natural gas, methanol, ethanol, and liquefied petroleum gas. During fiscal year 1993, the National Renewable Energy Laboratory has published and distributed two light-duty vehicle operational reports titled, "Alternative Motor Fuels Act of 1988 - Light-Duty Vehicle Summary Information and Individual Vehicle Graphs." The Department has also published quarterly information updates concerning the initiation, function, and operation of the Alternative Fuels Data Center. In addition to presenting reports, the Department has prepared a video explaining the operation and characteristics of using compressed natural gas as a fuel. Plans for videos about other fuels are in progress.

DOE, through the National Renewable Energy Laboratory, has established the Alternative Fuels Data Center to assemble and manage a series of data bases that document government and selected private fleet on-road alternative fuel vehicle performance. As of September 1993, 363 organizations have obtained data from the center. The distribution of these organizations are 28 in academia, 118 government agencies, 170 private industry, seven original equipment manufacturers, eight private citizens, and 32 research and consulting firms.

In addition, DOE established and operates a National Alternative Fuels Hotline. The toll-free number, 1-800-423-1DOE, is available to all callers outside the Washington, D.C., area (local callers may call (703) 528-3500 to reach the hotline). The hotline is available to callers between 10 a.m. and 6 p.m. Eastern Standard Time, on weekdays except Federal holidays. This hotline currently handles about 600 calls per month and provides such services as access to technical publications on alternative fuel topics; a free copy of Windows-based software that allows the caller to access and query the Alternative Fuels Data Center data base; a subscription to the Alternative Fuels Data Center Update quarterly newsletter; and a 20-page directory that provides over 8,000 contacts for government, industry, and academic alternative fuel participants.

Because alternative fuels and vehicles have unique characteristics in the areas of safety, handling, engine performance, and environment regulations, DOE is developing a certification requirement for training programs for technicians who install and maintain alternative fuel components. This work is being done cooperatively, with experts in alternative fuel vehicle design, fuel suppliers, technical curriculum designers, technical colleges, the Institute for Automotive Service Excellence, and government agencies developing these curricula, as well as developing a train-the-trainers program for alternative fuel vehicle maintenance.

Education of the current and next-generation automotive engineers about alternative fuel vehicle technology is being accomplished in cooperation with the Society of Automotive Engineers (SAE). TOPTECs are meetings held for transfer of the latest technologies on various SAE topics. DOE funds about four alternative fuel TOPTECs annually. These meetings are held in conjunction with universities across the country to increase students' awareness of, and interest in, alternative fuels and alternative fuel vehicles.

As an integral part of this effort to educate and stimulate the student engineers interest in alternative fuel vehicles, DOE co-funded the 1993 Natural Gas Vehicle Challenge student engineering competition. Students competing in the most recent Challenge represented schools in Canada and Mexico, as well as the United States. The top five U.S. universities have been sponsored to participate in the international Natural Gas Vehicle Showcase event to be held in Toronto, Canada, in 1994. To capitalize on the synergy between the SAE TOPTECs and student competitions, attempts have been made to schedule these events in tandem. Figure 7-1 shows a lineup of student entries at the 1993 Natural Gas Vehicle Challenge.

A major part of increasing the public awareness about the presence of alternative fuel vehicles is visibility of the vehicles themselves acting as traveling billboards. Each vehicle displays graphics which identify the vehicle as an alternative fuel vehicle and also displays the type of fuel being used. In addition to their external markings, many vehicles have internal materials such as owner's manual supplements that include operation, safety, and servicing information. Not only do the vehicles advertise alternative fuel use, but so do the refueling locations, which are also clearly marked and display fuel type, operating instructions, and safety precautions.

Figure 7-1. Student Competitors and Their Entries at the Natural Gas Vehicle Challenge Event

APPENDIX A

TECHNICAL CHARACTERISTICS OF VEHICLES PARTICIPATING IN THE FEDERAL ALTERNATIVE MOTOR FUELS PROGRAM

A.1 Technical Characteristics of Light Duty Vehicles

Currently, six vehicle models are represented in the program, the 1991/1992/1993 Chevrolet Lumina, 1992/1993 Chevrolet C2500 pickup truck, 1991/1992/1993 Ford Taurus, 1993 Dodge Spirit, 1993 Ford Econoline van, and 1992/1993 Dodge B-250/350 van. Although these vehicles outwardly appear no different from conventional gasoline vehicles, they incorporate various fuel system and engine modifications in order to operate on methanol/gasoline mixtures, ethanol/gasoline mixtures, and compressed natural gas fuel.

The unique components of the M85/E85 Chevrolet Lumina for operating on a mixture of methanol/gasoline or denatured ethanol/gasoline are shown in Figure A-1. Major changes include different piston rings, fuel tank, engine electronic control module, and the addition of a fuel sensor to determine the proportion of methanol or ethanol in the fuel mixture. The M85 Chevrolet Lumina is able to operate on fuel ranging from 85 percent methanol/15 percent gasoline to 100 percent gasoline. Similarly, the E85 Chevrolet Lumina is able to operate on fuel ranging from 85 percent ethanol/15 percent gasoline to 100 percent gasoline. The M85 Chevrolet Luminas refill at the same rate as the conventional gasoline vehicles.

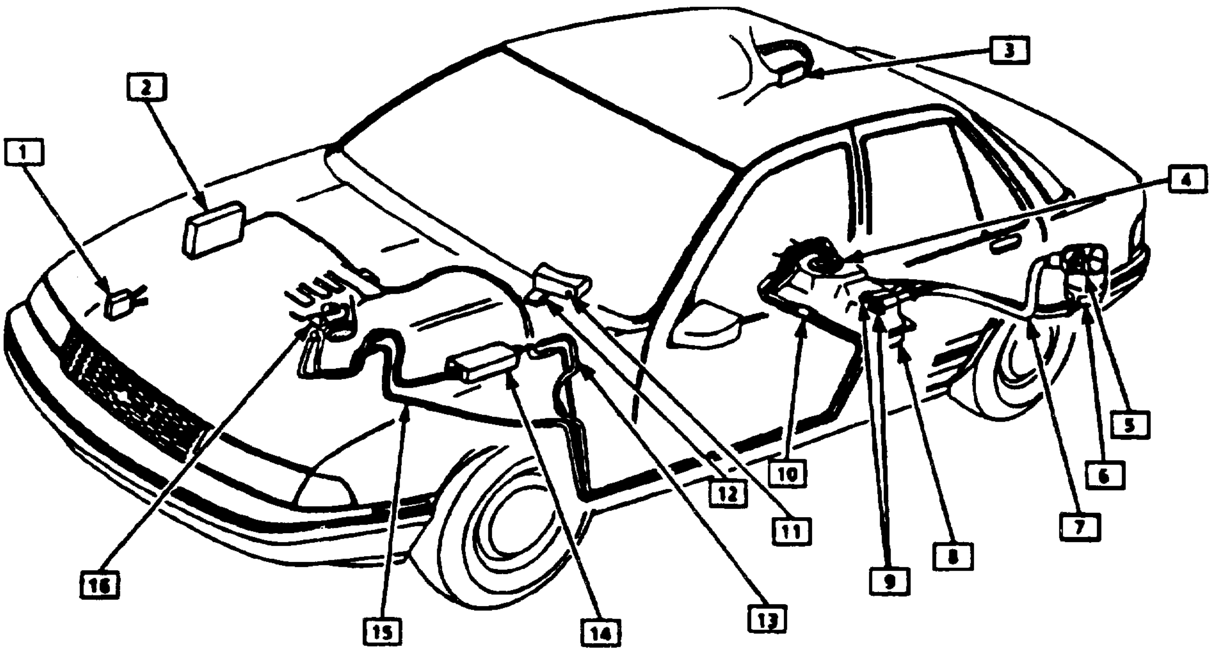
Unique components of the M85 Ford Taurus for operating on methanol and gasoline fuel blends are shown in Figure A-2. The major changes include different spark plugs, a fuel tank, engine electronic control module, and the addition of a sensor to determine the proportion of methanol in the fuel mixture. The M85 Ford Taurus operates on fuel mixtures ranging from 85 percent methanol/15 percent gasoline to 100 percent gasoline. The M85 Ford Taurus tank capacity is 2.6 gallons more than conventional vehicles.

The unique components of the M85 Ford Econoline van for operating on methanol and gasoline fuel blends are shown in Figure A-3. The major changes include engine modifications to increase durability and compatibility with methanol fuel, different spark plugs, fuel-tank electronic control module, and the addition of a sensor to determine the proportion of methanol in the fuel mixture. The M85 Ford Econoline is able to operate on mixtures ranging from 85 percent methanol/15 percent gasoline to 100 percent gasoline fuel.

Basic operation of the M85/E85 Chevrolet Lumina, M85 Ford Taurus, M85 Ford Econoline, and the Dodge M85 Spirit are unchanged from their conventional gasoline counterparts. All of the alternative fuel vehicle engine control systems for these vehicles continuously adjust the engine for proper performance regardless of the proportion of methanol/ethanol in the fuel. Because these adjustments do not require intervention by the driver, the only difference the driver may notice is a slight increase in vehicle response and acceleration with fuels of a high methanol/ethanol content.

Unique components of the Dodge B-250/350 and Chevrolet C2500 vehicles for operating on compressed natural gas are shown in Figures A-4 and A-5, respectively. Both the Dodge and Chevrolet vehicles have three pressurized compressed natural gas cylinders in place of the gasoline tank and are dedicated vehicles; that is, they only operate on natural gas. The time required to refuel the compressed natural gas vehicles is often longer than conventional gasoline vehicles, depending on whether the compressed natural gas

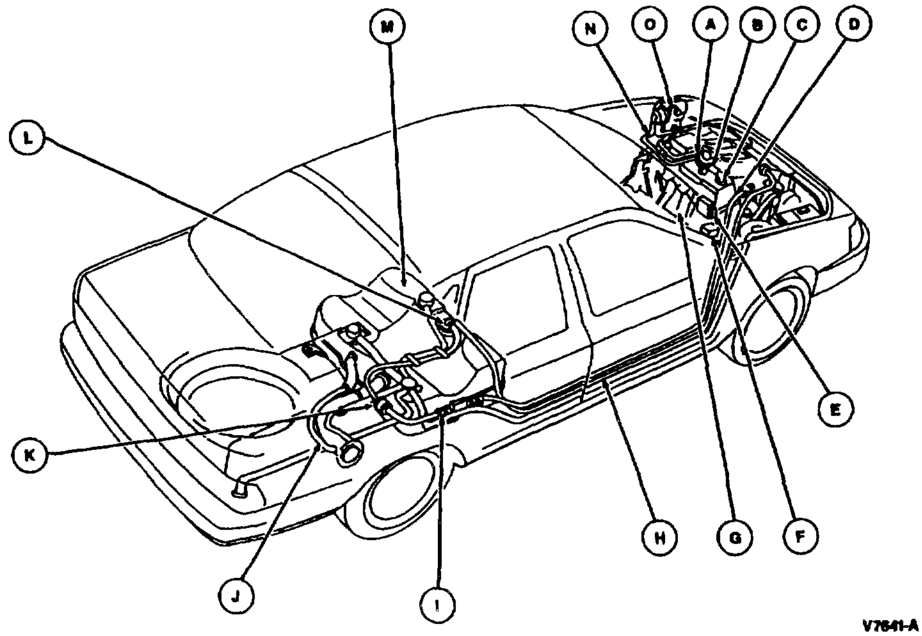
Figure A-1. Unique Components of the M85/E85 Chevrolet Lumina



1.	Remote Injector Driver	9.	Flame Arrestors
2.	Electronic Control Module (ECM)	10.	In-Line Fuel Filter
3.	Fuel Pump Speed Controller	11.	Low Fuel Light
4.	Fuel Sender Assembly	12.	Fuel Sender Control Module
5.	Fuel Filler Cap	13.	Fuel Feed
6.	Evaporative Canister	14.	Variable Fuel Sensor
7.	Fuel Tank Filler Neck	15.	Fuel Return
8.	Fuel Tank	16.	Fuel Rail Assembly

Source: General Motors Corporation

Figure A-2. Unique Components of the M85 Ford Taurus



Glossary of Components

A. **Spark Plugs:** The wire electrode is wider for increased heat transfer.

B. **Fuel Injectors:** FFV fuel injectors have a higher fuel flow capacity and a modified spray nozzle design.

C. **Fuel Rail:** Material changes are made for fuel methanol compatibility.

D. **Fuel Pressure Regulator:** Material changes are made for fuel methanol compatibility.

E. **EEC-IV Microprocessor:** A different calibration is used to monitor and activate FFV sensors and systems as required.

F. **Wiring Harnesses:** Wiring changes have been made to connect with the Fuel Sensor and Cold Start System.

G. **Engine Oil:** Specially formulated for required use with all of the possible fuel mixtures. Oil change intervals for fuel methanol vehicles are required every 4800 km (3000 miles).

H. **Fuel Supply, Return and Vapor Lines:** Material changes are made for methanol fuel compatibility.

I. **Fuel Sensor:** This unique FFV component allows the EEC-IV microprocessor to determine the percentage of methanol in the fuel.

J. **Filler Pipe:** Improved coating is applied and anti-siphon screen installed. Material changes are made for fuel methanol compatibility.

K. **Fuel Filter:** Material changes are made for fuel methanol compatibility.

L. **Fuel Pump Assembly/Fuel Sending Unit:** Nickel plating is applied to non-stainless steel parts. All other parts are of different materials for compatibility with methanol fuels.

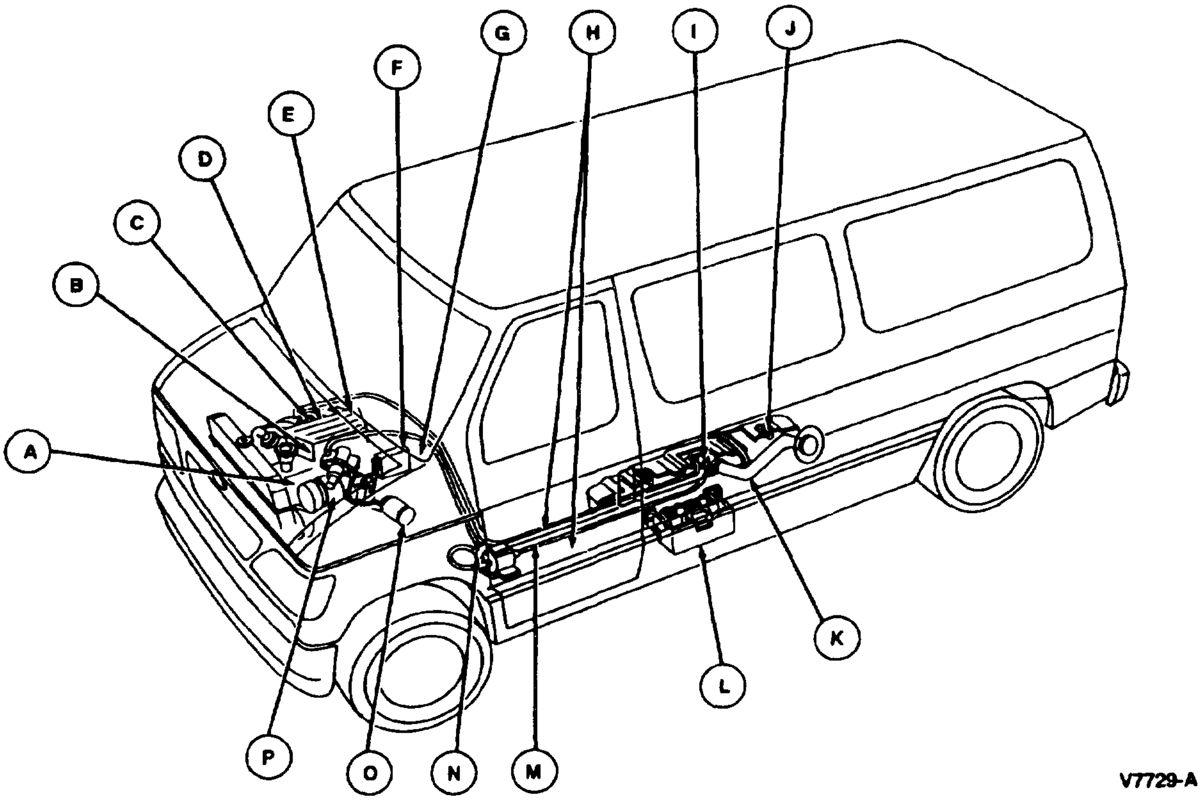
M. **Fuel Tank:** A high-density polyethylene fuel tank is used for fuel methanol compatibility and is shielded to reduce evaporation.

N. **Cold Start System:** Allows faster, more reliable starts in extremely cold temperatures.

O. **Evaporative Emission System:** Charcoal canister enlarged and vapor vent valves modified to relieve pressure from extended idling and hill climbing.

Source: Ford Motor Company

Figure A-3. Unique Components of the M85 Ford Econoline Van



Glossary of Components

A. **Engine**: The engine is designed for increased durability and compatibility with fuel methanol.

B. **Spark Plugs**: The wire electrode is wider for increased heat transfer.

C. **Fuel Injectors**: FF vehicle fuel injectors have a higher fuel flow capacity and a modified spray nozzle design.

D. **Fuel Pressure Regulator**: Material changes are made for fuel methanol compatibility.

E. **Mass Air/SFI**: The engine control system has been changed to a measured air flow design with sequential operation of the fuel injection.

F. **Powertrain Control Module (PCM)**: A different calibration is used to monitor and activate FF vehicle sensors and systems as required.

G. **Wiring Harnesses**: Wiring changes have been made to connect with the Fuel Sensor. Cold Start System and Air/Fuel Control Systems.

H. **Fuel Supply, Return and Vapor Lines**: Material changes are made for methanol fuel compatibility.

I. **Fuel Pump Assembly/Fuel Sending Unit**: Nickel plating is applied to non-stainless steel parts. All other parts are of different materials for compatibility with methanol fuels.

J. **Fuel Tank**: A coated steel fuel tank is used for fuel methanol compatibility and is shielded to reduce evaporation.

K. **Filler Pipe**: Improved coating is applied and anti-siphon screen installed. Material changes are made for fuel methanol compatibility.

L. **Evaporative Emission System**: Additional charcoal canisters (four total) have been added to relieve pressure from extended idling and hill climbing.

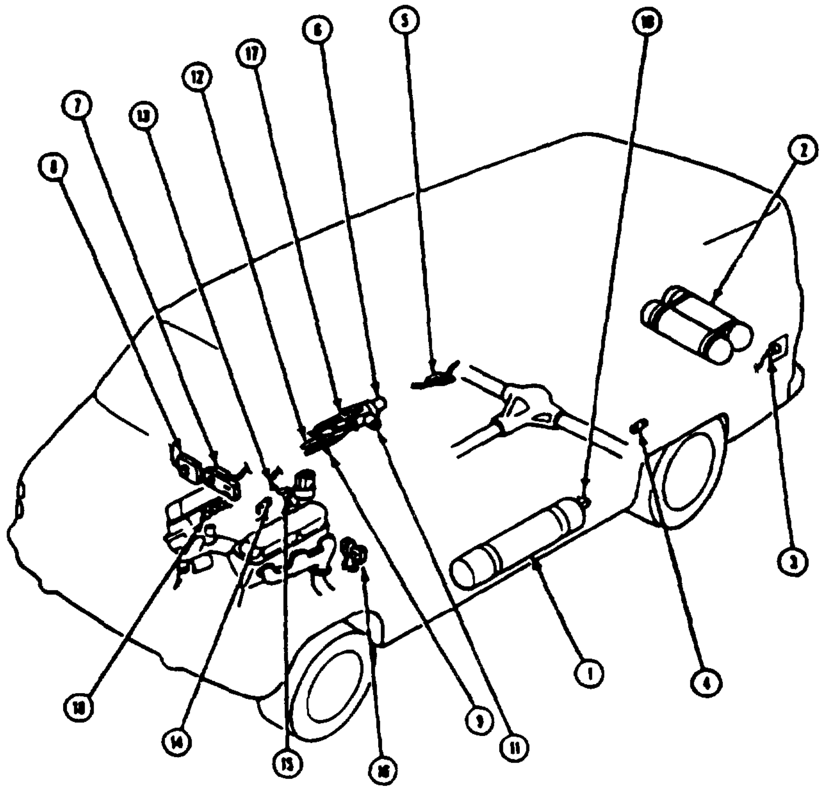
M. **Fuel Filter**: Material changes are made for fuel methanol compatibility.

N. **Engine Oil**: Specially formulated for required use with all of the possible fuel mixtures. Oil change intervals for Flexible Fuel vehicles are required every 4800 km (3000 miles).

O. **Fuel Sensor**: This unique FF vehicle component allows the powertrain control module to determine the percentage of methanol in the fuel.

P. **Cold Start System**: Allows faster, more reliable

Figure A-4. Unique Components of the Compressed Natural Gas Dodge B-250/350

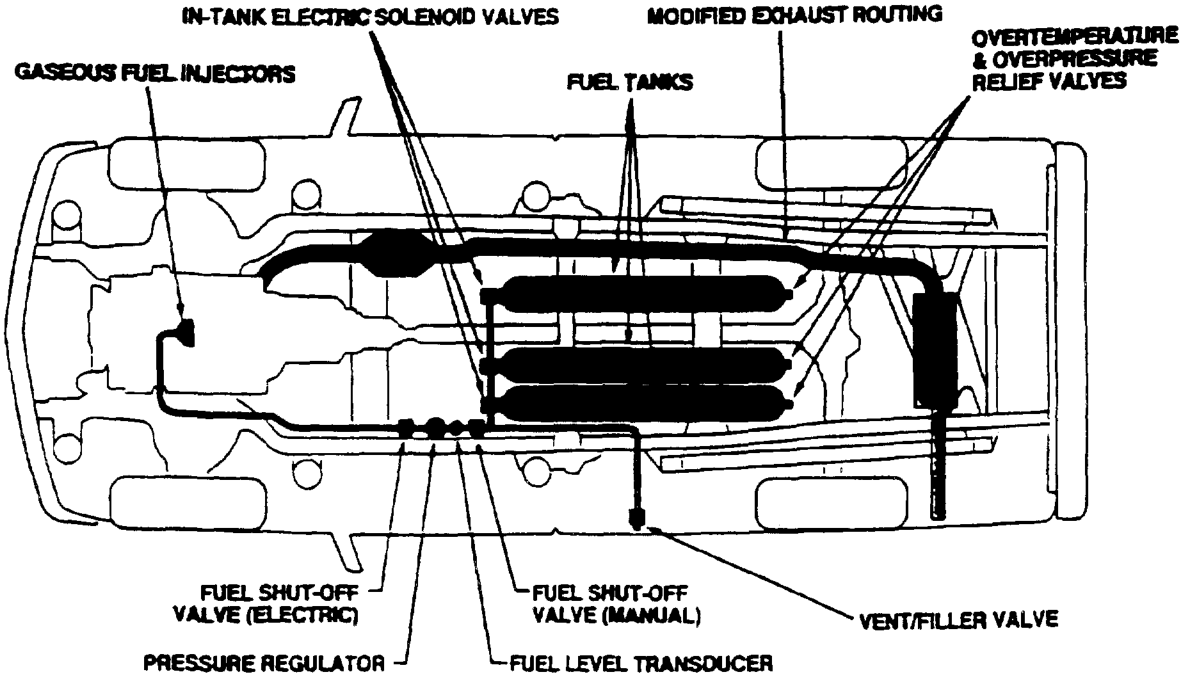


Glossary of Components

1. Fuel Cylinder (Side)
2. Fuel Cylinders (Rear)
3. Fuel Fill Receptacle
4. Check Valve
5. Manual Shut-Off Valve
6. Fuel Pressure Regulator
7. Powertrain Control Module
8. Fuel Injector Driver Module
9. Pressure Relief Discharge Tube
10. Fuel Gauge Pressure Sensor
11. High-Pressure Fuel Shut-off Solenoid
12. Engine Coolant Hoses (2)
13. Fuel Temperature Sensor
14. Fuel Pressure Sensor
15. Low-Pressure Fuel Shut-off Solenoid
16. Fuel Shut-off Solenoid Relay
17. Pressure Relief Device
18. Fuel Injectors (8)

Source: Chrysler Corporation

Figure A-5. Unique Components of the Compressed Natural Gas Chevrolet C2500 Pickup Truck



vehicles are refueled from a time-fill or fast-fill refueling station. With fast-fill, refueling occurs in a time period slightly longer than conventional liquid-fuel vehicles. Time-fill refueling relies only on the compressor itself and may take several hours to complete. This is dependent on compressor operating capacity and the number of vehicles being refueled at one time. With time-fill, the vehicles are typically parked and refueled overnight. However, most of the compressed natural gas vehicles participating in the light-duty vehicle program are located near refueling facilities that have fast-fill capability.

A.2 Technical Characteristics of Truck Commercial Vehicles

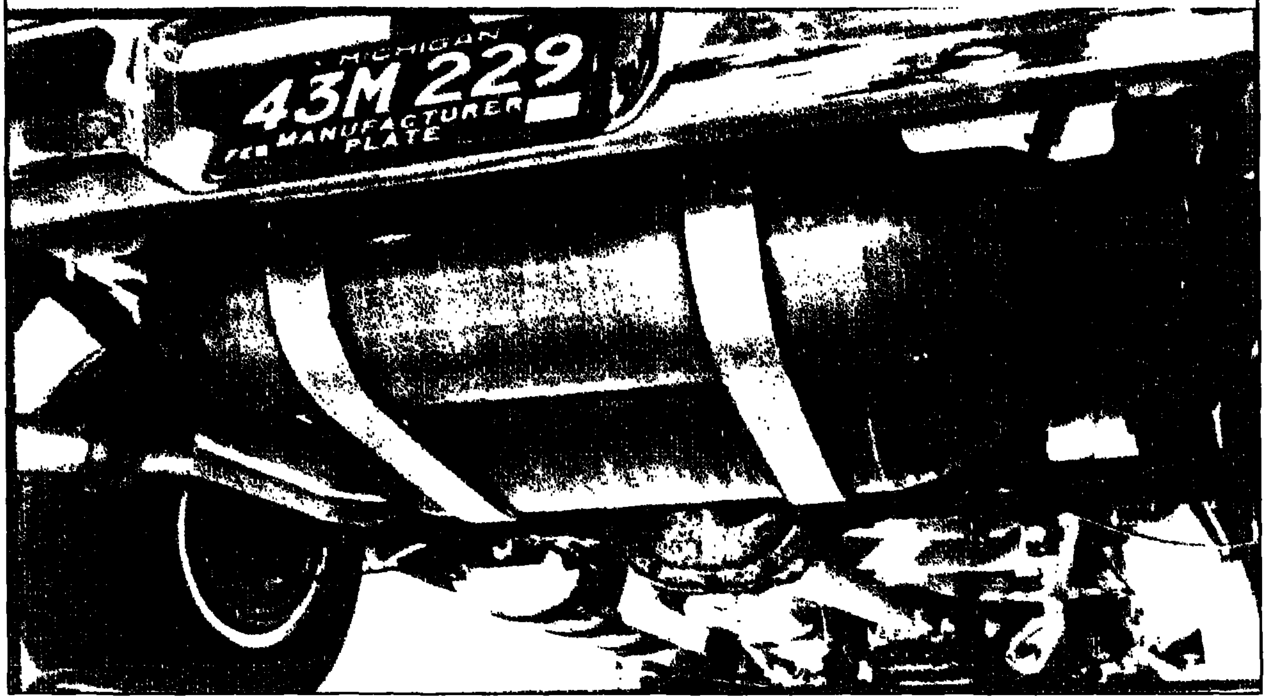
A variety of turbocharged engine technologies are being used in the Alternative Fuels Truck Commercial Applications Project. The vehicles operating on ethanol use the Detroit Diesel 6V92 engine. These engines are derived from Detroit Diesel's commercial two-stroke cycle methanol engine that has been designed for bus applications. The engine has been slightly modified to accommodate the differences in fuel properties between ethanol and methanol.

The Caterpillar G3406 natural gas engine is derived from Caterpillar's 3406 commercial diesel engine. The G3406 engine incorporates a lean-burn spark-ignition combustion technology based on the natural gas engine technology that has been used for many years by Caterpillar in stationary engine applications.

The Cummins L10 engine is a lean-burn spark-ignition natural gas engine that was developed for bus applications. The engine is now a commercialized natural gas engine derived from the Cummins L10 diesel version.

The engines operating on gaseous fuels are original-equipment gasoline versions that have been modified by the original equipment manufacturers, in cooperation with alternative fuel system manufacturers, for operation on fuels such as propane and natural gas. For the natural gas vehicles, fuel is carried onboard the vehicles in lightweight high-pressure tanks. Figure A-6 shows a typical installation of compressed natural gas tanks under a Dodge B250 van. Fuel for the propane vehicles is stored as a liquid onboard the vehicle in moderate-pressure steel tanks.

Figure A-6. Typical Installation of Compressed Natural Gas Fuel Tanks Under a Dodge B250 Van



The M85 vehicles used in the Federal Express fleets are original equipment flexible-fuel or variable-fuel vehicles that are designed to operate on M85 or any mixture of gasoline and methanol from 100 percent gasoline down to the 15 percent gasoline and 85 percent methanol mixture. In this fleet, the methanol vehicles operate 100 percent of the time on M85. The overall Federal Express fleet of pick-up and delivery vehicles include original-equipment 1992-model-year vehicles from Chevrolet Motor Division of General Motors Corporation, Ford Motor Company, and Chrysler Corporation.

The two electric vehicles used in the Federal Express fleet are 1990-model-year full-sized electric G-vans that have been produced by Conceptor, a Division of Vehma

International. Due to the limited range of these electric vehicles, they are used exclusively in short-trip operations and accumulate very little mileage.

A.3 Technical Characteristics of Transit Bus Engines and Fuel Systems

Detroit Diesel Corporation has developed and commercialized a two-stroke cycle compression-ignition bus engine product line that can operate on M100 or M85. This engine was developed by modifying a two-stroke cycle diesel engine product line that has been in service for many years. The primary difference is a compression ratio raised from 19:1 for the diesel engine to 23:1 for the methanol engine, an electronically controlled bypass scavenge blower, glow plugs for cold-start and warmup, methanol-compatible materials in the fuel system, and larger-capacity fuel injectors to accommodate the lower volumetric energy value of methanol as compared to diesel fuel. Shown in Figure A-7 is a photograph of the Detroit Diesel 6V-92TA engine. The Detroit Diesel ethanol engine used in some of the transit-bus demonstration fleets is a modified methanol engine and has been certified for emissions.

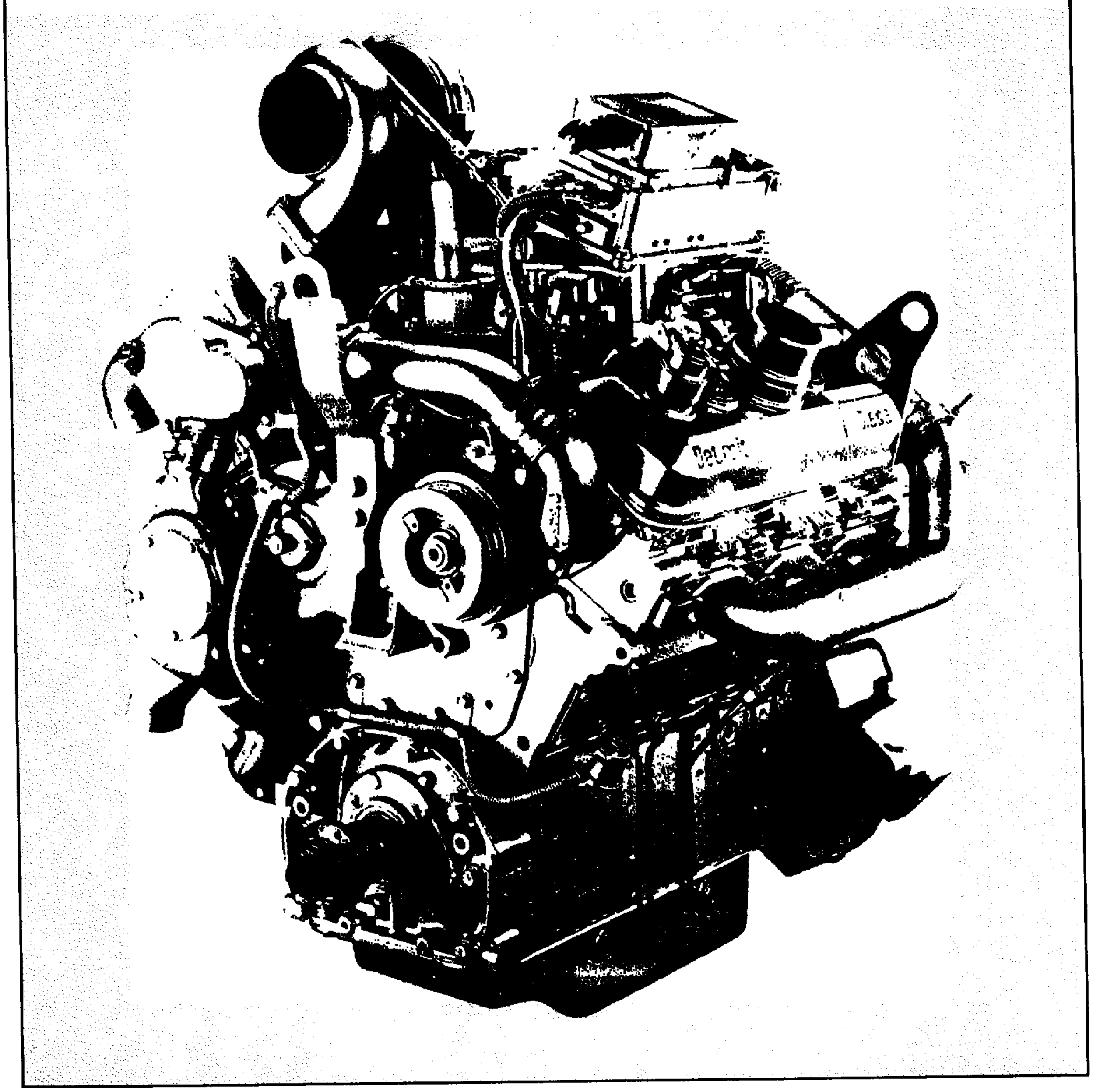
The vehicle fuel systems for the methanol and ethanol buses are similar to that of the diesel buses with the exception that the alcohol fuel tanks and other fuel system components must be manufactured from alcohol-compatible materials. In addition, alcohol fuel tanks are sized to account for the differences in energy density between alcohol and diesel fuels such that the vehicle driving range between refueling is comparable.

The natural gas engines used in DOE's current demonstration program are manufactured by both Detroit Diesel and Cummins. One version of the Detroit Diesel natural gas engine is a pilot-injection natural gas engine that has been adapted from a technology used for large natural gas engines in stationary applications. The pilot-injection natural gas bus engine is a 6V-92 two-stroke cycle engines, where natural gas is injected directly into the cylinder during the compression stroke. Near the end of the compression stroke, a small amount of diesel fuel is injected through the normal diesel fuel-injection system providing the ignition source for the natural gas and air mixture that is already in the cylinder. Although this engine is still in production, it tends to emit higher levels of total hydrocarbons (discussed in the emissions section) when compared to spark-ignition natural gas engines. However, this pilot-injection natural gas engine provides better idle and part-load efficiency than the spark-ignition natural gas engines because, like the diesel engine, it is unthrottled at idle and part-load.

The Cummins L10 natural gas engine is a dedicated natural gas engine. It is a 6-cylinder inline heavy-duty engine derived from the Cummins L10 diesel engine. The diesel injection system is replaced by a natural gas system with carburetor, governor, and a spark-ignition system. Figure A-8 is a photograph of the Cummins L10 dedicated natural gas bus engine.

Other engine manufacturers that are involved in producing dedicated spark-ignition natural gas engines using similar technology include Detroit Diesel Corporation (Series 50 engine), Detroit Diesel Corporation/Navistar International (Series 30 engine), and Hercules Engines, Inc. In addition, Tecodrive produces dedicated natural gas engines that use similar

Figure A-7. The Detroit Diesel 6V-92TA Methanol Bus Engine
(Photo from Detroit Diesel Information Update)



technology. The primary differences between natural gas and diesel buses are the fuel tanks and other fuel system components.

The configuration of compressed natural gas transit buses may vary, depending on the manufacturer, but the fuel-system components will be similar to those shown in Figure A-9. Liquefied natural gas buses are similar to the compressed natural gas buses, with the exception of the fuel tanks and some fuel-system components.

Figure A-8. Cummins Natural Gas Bus Engine (Photo from Cummins Brochure)

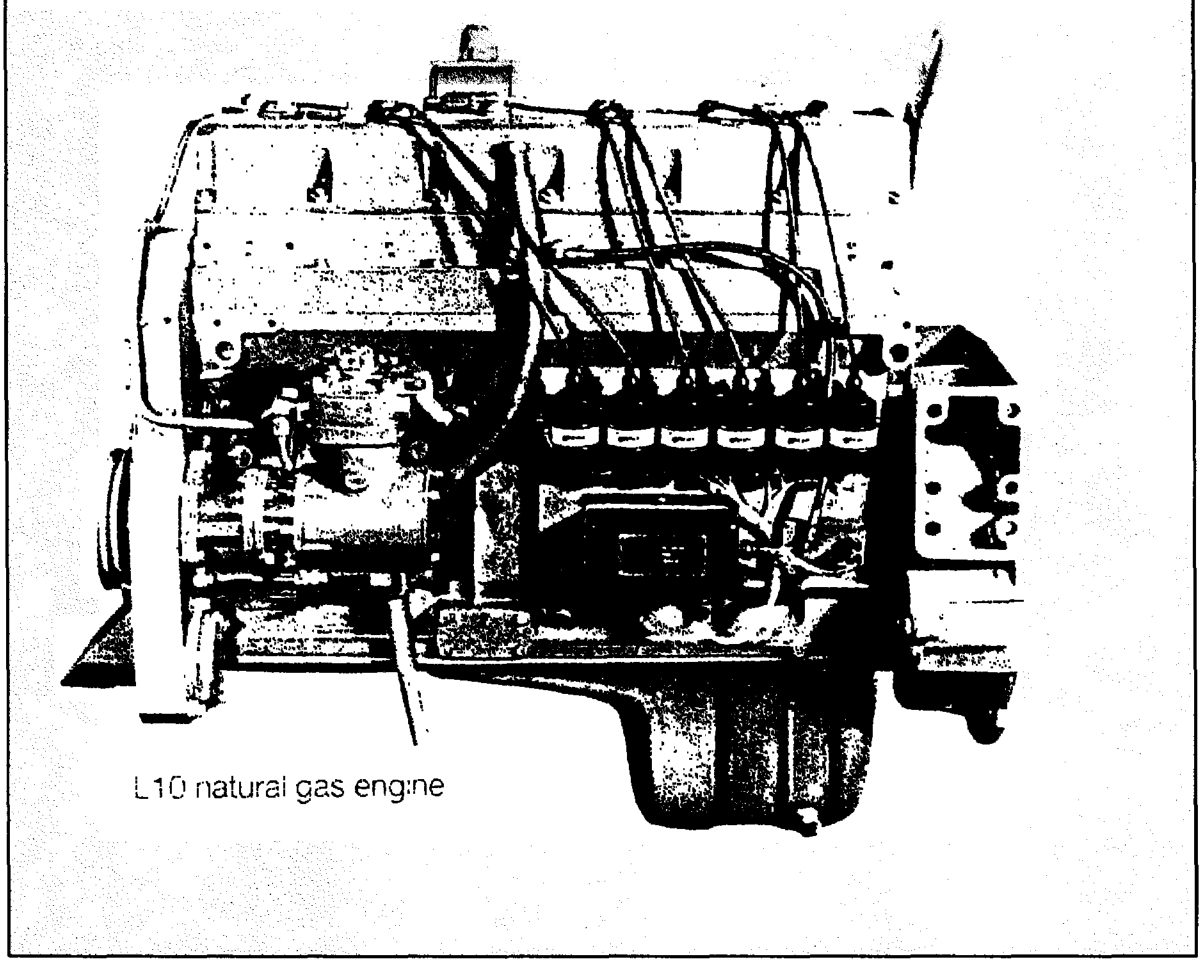


Figure A-9. Unique Components of a Compressed Natural Gas Transit Bus