Alternative Fuels for Vehicles Fleet Demonstration Program

Volume 1: Summary

Final Report 97-4
March 1997

New York State
Energy Research and Development Authority

NYSERDA

The New York State Energy Research and Development Authority (NYSERDA) is a public benefit corporation created in 1975 by the New York State Legislature.

NYSERDA has major programs in energy and environmental research, radioactive and hazardous waste management, tax-exempt bond financing, energy analysis and planning, and energy efficiency grants. Its responsibilities include:

- Conducting a multifaceted energy and environmental research and development program to meet New York State's diverse needs;
- Helping industries, schools, hospitals, and not-for-profits implement energy efficiency measures;
- Providing objective, credible, and useful energy analysis to guide decisions made by major energy stakeholders in the private and public sectors;
- Managing the Western New York Nuclear Service Center at West Valley, including: (1) overseeing the State's interests and share of costs at the West Valley Demonstration Project, a federal/State radioactive waste clean-up effort, and (2) managing wastes and maintaining facilities at the shut-down State-Licensed Disposal Area;
- Participating in the Malta Rocket Fuel Area "Superfund" site clean-up and managing facilities at the site on behalf of the State;
- Coordinating the State's activities on nuclear matters, and designing, constructing, and operating State facilities for disposal of low-level radioactive waste, once siting and technology decisions are made by the State; and
- Financing energy-related projects, reducing costs for ratepayers.

NYSERDA derives its basic research revenues from an assessment levied on the intrastate sales of New York State's investor-owned electric and gas utilities. Additional research dollars come from limited corporate funds and a voluntary annual contribution by the New York Power Authority. More than 300 of NYSERDA's research projects help the State's businesses and municipalities with their energy and environmental problems and, of these, 185 are developing energy or environmental products that could be manufactured in the State. These contributions to the State's economic growth and environmental protection are made at a cost of less than $1 per New York resident per year.

Federally funded, the Energy Efficiency Services program is working with another 228 businesses, schools, and municipalities to identify existing technologies and equipment to reduce their energy costs.

For more information, contact the Technical Communications unit, NYSERDA, Corporate Plaza West, 286 Washington Avenue Extension, Albany, New York 12203-6399; (518) 862-1090, ext. 3250; or on the World Wide Web at http://www.nyserda.org/

March 1997

ALTERNATIVE FUELS FOR VEHICLES FLEET DEMONSTRATION PROGRAM

Final Report

Volume 1: Summary

Prepared for

THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

Joseph R. Wagner
Senior Project Manager

Prepared by

EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.
8401 Colesville Road, Suite 500
Silver Spring, Maryland 20910

Richard L. Bechtold, P.E.
Project Manager

1614-ERER-ER-91

NYSERDA
Report 97-4

March 1997

NOTICE

DISCLAIMER

ABSTRACT

The Alternative Fuels for Vehicles Fleet Demonstration Program (AFV-FDP) was a multiyear effort to collect technical data for use in determining the costs and benefits of alternative-fuel vehicles in typical applications in New York State. During 3 years of collecting data, 7.3 million miles of driving were accumulated, 1003 chassis-dynamometer emissions tests were performed, 862,000 gallons of conventional fuel were saved, and unique information was developed about garage safety recommendations, vehicle performance, and other topics. Findings are organized by vehicle and fuel type. For light-duty compressed natural gas (CNG) vehicles, technology has evolved rapidly and closed-loop, electronically-controlled fuel systems provide performance and emissions advantages over open-loop, mechanical systems. The best CNG technology produces consistently low tailpipe emissions versus gasoline, and can eliminate evaporative emissions. Reduced driving range remains the largest physical drawback. Fuel cost is low ($/Btu) but capital costs are high, indicating that economics are best with vehicles that are used intensively. Propane produces impacts similar to CNG and is less expensive to implement, but fuel cost is higher than gasoline and safety codes limit use in urban areas. Light-duty methanol/ethanol vehicles provide performance and emissions benefits over gasoline with little impact on capital costs, but fuel costs are high. Heavy-duty CNG engines are evolving rapidly and provide large reductions in emissions versus diesel. Capital costs are high for CNG buses and fuel efficiency is reduced, but the fuel is less expensive and overall operating costs are about equal to those of diesel buses. Methanol buses provide performance and emissions benefits versus diesel, but fuel costs are high. Other emerging technologies were also evaluated, including electric vehicles, hybrid-electric vehicles, and fuel cells.

Keywords: Alternate fuel vehicles, compressed natural gas, ethanol, methanol, electric vehicles

TABLE OF CONTENTS

Section	Page
SUMMARY	S-1
1 INTRODUCTION	1-1
2 AFV-FDP METHODOLOGY	2-1
3 AFV-FDP FINDINGS	3-1
LIGHT-DUTY AFVs	3-1
Natural Gas	3-1
Methanol and Ethanol	3-17
LPG/Propane	3-28
HEAVY-DUTY AFVs	3-35
Natural Gas	3-35
Methanol and Ethanol	3-41
LPG/Propane	3-44
OTHER ALTERNATIVE FUELS AND AFVs	3-45
Biodiesel	3-45
Electric Vehicles	3-45
Hydrogen and Fuel Cells	3-49
Hybrid-Electric Vehicles	3-50
4 AFV STATUS	4-1
AFV TECHNOLOGY STATUS AND VEHICLE COST	4-1
AFV TECHNOLOGY DEVELOPERS IN NEW YORK STATE	4-2
NEW YORK STATE AFV POPULATION	4-3
NEW YORK CITY'S ALTERNATIVE-FUEL PROGRAM	4-5
CLEAN-FUEL TAXI PROGRAM	4-6
5 GLOSSARY	5-1
6 REFERENCES	6-1

FIGURES

Figure		Page
3.1	U.S. Postal Service CNG Vans on Staten Island	3-2
3.2	Volume Needed to Store Equal Amounts of Energy, CNG Compared to Gasoline (Fuel Only, No Hardware)	3-4
3.3	Typical CNG Cylinder Weights Per Gallon Storage Volume (3,600 psi Cylinders)	3-4
3.4	Typical CNG Cylinder Cost Per Gallon Capacity (3,600 psi Cylinders)	3-5
3.5	Typical CNG Fuel System Pickup Truck Installation	3-6
3.6	Light-Duty CNG Vehicle Exhaust Emissions	3-11
3.7	CNG Refueling Facilities in New York State	3-14
3.8	New York State Thruway Authority Methanol Flexible-Fuel Ford Taurus and M85 Refueling Facility	3-18
3.9	1996 Ford Taurus Changes to Use M85 or E85	3-22
3.10	1993 Taurus FFV Exhaust Emissions	3-25
3.11	M85 Refueling Facilities in New York State	3-26
3.12	Light-Duty Propane Vehicle Exhaust Emissions	3-32
3.13	Refueling an OPRHP Propane Vehicle	3-33
3.14	Propane-Refueling Nozzle	3-33
3.15	The Cummins L10G Engine used in Natural Gas Transit Buses	3-36
3.16	Long Island Bus CNG Transit Buses	3-36
3.17	Average Transit Bus Emissions Using the New York City Bus Cycle (Long Island Bus CNG and Diesel Buses)	3-39
3.18	DDC Heavy-Duty Methanol Engine	3-43
3.19	GM's EV1 Electric Vehicle	3-46
3.20	Volume Needed to Store Equal Amounts of Energy, Hydrogen Compared to Gasoline (Fuel Only, No Hardware)	3-51
3.21	Orion II Hybrid-Electric Bus	3-52
3.22	Schematic of the Orion VI Hybrid-Electric Bus Powertrain	3-53

TABLES

Table		Page
2.1	Fleet Operators Participating in the AFV-FDP	2-1
2.2	AFVs by Vehicle and Fuel Type	2-3
3.1	Comparison of Typical Natural Gas and Gasoline Properties	3-2
3.2	Comparison of OEM and Converted Dedicated CNG Dodge Vans	3-8
3.3	Annual Miles Traveled to Achieve Three-Year Simple Payback of a CNG Fuel System[1] at Various Fuel Economies and Equivalent Gallon CNG Price Differentials	3-9
3.4	ULEV Emissions Regulations	3-12
3.5	CNG Vehicle Attributes Relative to Gasoline Vehicles	3-16
3.6	Properties of Methanol and Ethanol, Compared to Gasoline	3-18
3.7	ASTM Methanol and Ethanol Volatility Classes	3-20
3.8	Methanol FFV[1] Attributes Relative to Gasoline Vehicles	3-27
3.9	Properties of Propane, Compared to Gasoline	3-29
3.10	Light-Duty Dedicated Propane Vehicle Attributes Relative to Gasoline Vehicles	3-35
4.1	Typical Incremental Prices of AFVs	4-3
4.2	Examples of Companies in New York State Providing AFV Products or Services	4-4
4.3	NYC AFVs in Operation as of 1995	4-6

SUMMARY

The use of alternative fuels in vehicles offers potential environmental, energy security, and economic benefits to New York State. To evaluate the costs and benefits of these fuels, the New York State Energy Research and Development Authority (NYSERDA) undertook the Alternative Fuels for Vehicles Fleet Demonstration Program (AFV-FDP). Fuels evaluated were compressed natural gas (CNG), electricity, ethanol, methanol, and propane.

This report describes the AFV-FDP, summarizes its findings, reviews the status of alternative fuel vehicle (AFV) technology, and briefly outlines AFV activity by manufacturers and others in the State. The AFV-FDP was designed to develop technical data that will assist State and local policy makers in determining the contribution that alternative fuels can make to achieving three major objectives:

- Improving air quality, especially in urban areas, and meeting National Ambient Air Quality Standards (NAAQS);
- Diversifying the State's fuel supply mix by reducing the transportation sector's dependence on petroleum; and
- Creating growth for companies in the State that produce AFVs, AFV components, and infrastructure equipment.

The AFV-FDP relied on State-local-national government partnerships to place AFVs in 21 fleets across the State. Over a five-year period, the 257 AFVs that were evaluated as part of this program logged more than seven million miles of driving and were subjected to extensive emissions tests and other data collection activities. Use of alternative fuels by these vehicles reduced gasoline and diesel fuel consumption by about 862,000 gallons during the data collection period. The majority of the vehicles remain in operation, continuing to displace petroleum while reducing pollution and demonstrating AFV capabilities.

BACKGROUND

New York State faces several environmental and regulatory challenges that may be met in part by use of alternative fuels. New York City and other metropolitan areas in the State currently have great difficulty in attaining compliance with the NAAQS for carbon monoxide, ground-level ozone, and particulate matter. If proposed changes in the NAAQS are enacted, large parts of the State will be in "non-attainment" for these pollutants, the adverse health effects of which, especially on children and the elderly, are well documented. Other consequences for not meeting NAAQS could include loss of federal highway funds and restrictions on business growth. Also, state fleets are among the first to fall under the mandates of the federal Energy Policy Act of 1992 (EPACT), which promotes the replacement of petroleum fuels with fuels that reduce oil imports, improve economic health, and reduce greenhouse gas emissions. Plus, the federal Clean Air Act Amendments of 1990 mandate purchase of clean-fuel vehicles by government agencies in severe non-attainment areas.

Building on a variety of smaller projects started in the 1980s, the AFV-FDP was officially launched in 1989. The vehicle fleets that participated were predominantly from State agencies and local governments. Cooperative agreements were established with each fleet operator to share the costs of acquiring AFVs, purchasing fuels, establishing refueling facilities, evaluating the need for garage safety modifications, training drivers and mechanics, collecting vehicle performance and emissions data, and resolving any problems encountered. Vehicles in the program included passenger cars, light-duty trucks and vans, school buses, and transit buses.

One of the major challenges faced by the AFV-FDP was the rapid evolution of AFV technology. The program's approach generally was to use commercially available AFV equipment to replicate the experience of typical AFV users, and to use a mix of standard-design and advanced-design components to gain an understanding of the costs and benefits of innovations that have become available in the marketplace. In some cases, experimental or limited-edition prototype equipment was used to provide insight into future technology. The program itself became a source of technical innovations, especially in the areas of refueling equipment and garage safety. The costs, benefits, and operating characteristics of AFVs were presented to the public and fleet operators in a series of educational efforts.

FINDINGS OF THE AFV-FDP

Key findings of the demonstration program are listed below:

Light-Duty Vehicles Using Compressed Natural Gas (CNG)

The technology has evolved rapidly. The newer closed-loop, electronic-control fuel systems (especially on factory-built, dedicated CNG vehicles) provide performance and emissions advantages over open-loop, mechanical systems, which in the AFV-FDP were found to produce highly variable emissions. The best CNG technology produces consistently low tailpipe emissions and can eliminate other types of emissions (evaporative, refueling, and running losses). Compared to gasoline, overall ozone-forming potential can be reduced by up to 85%. The most significant drawback is reduced driving range. Fuel cost is low, but vehicle capital costs are high, indicating that economics are best with vehicles that are used intensively. The high cost of refueling equipment has discouraged establishment of CNG refueling stations.

Light-Duty Vehicles Using Methanol or Ethanol

Alcohol fuels (methanol and ethanol) provide performance and emission benefits over gasoline with little impact on capital cost. Development of flexible-fuel vehicles (which allow alcohols to be intermingled with gasoline, in any proportion) has enabled deployment of alcohol vehicles with little alcohol refueling infrastructure in place. The main drawback is that alcohols cost much more than gasoline. Reducing this cost difference would require large investments in production facilities and, in the case of ethanol, breakthroughs in production technology.

Light-Duty Vehicles Using Propane (Liquefied Petroleum Gas)

Propane produces benefits similar to CNG and is less expensive to implement. Fuel costs are generally higher than for gasoline and current safety codes limit the use of propane in urban areas of New York State.

Light-Duty Vehicles Using Electricity

One electric vehicle was purchased by NYSERDA as part of the AFV-FDP. Performance in urban driving was adequate, but reduced range, poor cold-weather performance, and high capital cost were found to be disadvantages of commercially-available, electric-vehicle technology.

Heavy-Duty Vehicles Using Compressed Natural Gas

In a relatively short period, manufacturers have developed natural gas engines that rival the power, durability, and other desirable attributes of diesel engines, while providing large reductions in emissions of particulates and ozone-precursors. Capital costs for heavy-duty CNG vehicles are high and fuel efficiency is reduced, but the fuel is less expensive and overall operating costs are about equal to those of diesel vehicles.

Heavy-Duty Vehicles Using Methanol

Methanol buses provide performance and emission benefits compared to diesel buses, but high fuel costs have discouraged commercialization efforts.

STATUS OF AFV TECHNOLOGY

Development of alternative-fuel technology has not been uniform across the different types of fuel. Vehicle manufacturers have demonstrated the ability to build alcohol-fueled vehicles that provide good performance, low emissions, and little impact on vehicle price. CNG vehicle technology is maturing quickly and manufacturers have shown they can build, albeit at a significant cost premium, CNG vehicles that perform well and reduce emissions of ozone-precursors and particulates to extraordinarily low levels. Propane technology appears less mature, but the same technology used with CNG is easily transferable to propane vehicles.

Electric vehicle technology requires much more development to compete effectively with conventional vehicles. The primary component requiring development is the battery: cost and weight must be reduced, while energy-storage, power-output, and operating life must be increased. Major national efforts are focused on these objectives. Hybrid-electric vehicles (HEVs) overcome the limitations of pure electric vehicles and are now entering the marketplace. Recent demonstrations indicate HEVs may have basic economic and environmental advantages over other technologies in many applications. Fuel-cell technology shows long-range promise of providing high-efficiency, very-low-emission powerplants capable of using hydrogen and other fuels.

New York State is a leader in AFV technology. Many manufacturers in the State are developing AFVs and AFV components, and a not-for-profit Advanced Vehicle Technology Center has been established in Rome to assist companies in launching new product initiatives. Gas and electric utilities in the State also have been active in supporting AFV technology development and establishing the necessary infrastructure. They have acquired large numbers of AFVs for use in their own fleets and have sponsored many demonstration projects.

Current estimates of the number of AFVs and AFV refueling stations in New York State include: about 200 methanol vehicles, primarily flexible-fuel passenger cars but including 18 transit buses in New York City; approximately 2,600 CNG vehicles of all types; between 5,000 and 10,000 propane vehicles, mostly light trucks; and 11 methanol stations, 47 CNG stations, and about 150 propane stations. As for the future, EPACT and other federal requirements, as well as New York State's zero-emission vehicle (ZEV) regulations, are estimated to provide significant impetus for increased use of AFVs in the State. New York City has set a goal of 36,000 AFVs operating in the City by the end of 1998 and NYSERDA is facilitating a local-State-federal effort to convert a significant portion of the New York City taxi fleet to CNG. (In addition, as this report goes to press, plans are being developed to launch new AFV initiatives under the State's recently passed Environmental Bond Act.)

The AFV-FDP helped lay the groundwork for these and other AFV implementation efforts across New York State.

Section 1

INTRODUCTION

The 10 million highway vehicles operating in New York State impose severe environmental burdens and consume fuels that are almost entirely derived from petroleum. Many alternative fuels have been proposed to reduce environmental impacts and help diversify the State's fuel supplies, and to provide economic development benefits as well. This report summarizes results of the Alternative Fuels for Vehicles Fleet Demonstration Program (AFV-FDP), a multiyear effort to collect technical data for use in determining costs and benefits of alternative fuels used in typical applications in New York State. The AFV-FDP was managed by the New York State Energy Research and Development Authority (NYSERDA), with participation by local, State, and federal government agencies, and in cooperation with equipment manufacturers and fuel providers.

Volume 1 of this report provides: (1) information about the purpose and scope of the AFV-FDP; (2) a summary of AFV-FDP findings organized on the basis of vehicle type and fuel type; (3) a short review of the status of AFV technology development, including examples of companies in the State that are active in developing AFVs and AFV components; and (4) a brief overview of the status of AFV deployment in the State. Volume 2 contains appendices that provide supplemental information on key topics surrounding AFVs. Volume 3 provides expanded reporting of AFV-FDP technical details, including the compete texts of the brochure *Garage Guidelines for Alternative Fuels* and the technical report *Fleet Experience Survey Report*, plus an extensive glossary of AFV terminology.[1]

Over the past 25 years, New York State has made significant progress toward improving air quality. Since 1970, federal and State regulations have required air pollution reductions from electric power plants, factories, and motor vehicles. However, the New York City metropolitan area and several upstate areas are still in "non-attainment" of federal air quality standards (National Ambient Air Quality Standards or NAAQS) for carbon monoxide and

> EPA Proposes Revised Ozone and Particulate Standards
>
> EPA has re-evaluated the ozone and particulate standards and has proposed regulations more stringent than the present standards. If adopted as originally proposed, the revised standards will likely cause all of New York State to be in non-attainment for ozone. EPA's proposed new standard for particulates focuses on those less than 2.5 microns in diameter; this more stringent standard would put places such as New York City in non-attainment. Vehicles are major producers of ozone-forming emissions and diesel engines produce large amounts of particulates smaller than 2.5 microns.
>
> (Federal Register, Vol 61, No. 241, Friday, December 13, 1996, pp. 65638-65872)

[1]Also note that Volume 1 contains a brief glossary of terms used in Volumes 1 and 2.

ground-level ozone or "smog." (See Appendix A for additional information about New York State vehicle emission regulations and Appendix B for an explanation of how ozone is formed and its health effects.) The American Lung Association estimates that 2.5 million residents of the State under 13 years of age and 1.8 million over 65 years of age could experience adverse health consequences due to ozone [1].[2] Continued failure to meet the NAAQS could adversely affect the State's public health and, per federal law, also could result in the loss of federal highway funds and restrictions on business growth.

Emissions from millions of cars and light-duty trucks, almost exclusively operating on gasoline and diesel fuel, are major contributors to this problem (see Appendix C). In addition, heavy-duty trucks and buses using diesel fuel are a major source of particulates (small unburned particles of hydrocarbons and sulfur) and nitrogen oxide emissions in urban areas. Particulates are a special concern because the public is frequently exposed to them and current research suggests significant respiratory problems and cancer-causing potential from particulates (see Appendix D). New York City is barely complying with current particulate regulations, largely because of emissions from diesel buses. The U.S. Environmental Protection Agency (EPA) proposes to tighten the air quality standards for both ozone and particulates, potentially causing New York City and many other areas in the State to be placed out of compliance.

Interest in reducing carbon dioxide (CO_2) emissions also has grown in recent years. In February 1989, the State held a conference on global warming that identified CO_2 as the primary "greenhouse gas" contributor to the phenomenon. The current edition of the New York State Energy Plan (1994) warns that CO_2 emissions from motor vehicles in New York State will increase by 29% over the next 20 years as the number of vehicle-miles traveled increases 44% (from 109.8 billion to 157.6 billion). Combustion of alternative fuels results

<u>The Many Types of Gasoline</u>

In recent years, air pollution control efforts have dictated creation of new types of gasoline. The three major gasoline types now available are: reformulated, oxygenated, and conventional. None of these are considered to be alternative fuels, but they affect the baseline against which alternative fuels are compared. Reformulated gasoline is specifically tailored to reduce emissions that produce ozone. It typically contains some oxygenates such as ethers made from methanol (MTBE), although ethanol is also used. Reformulated gasoline must be used in urban areas around the U.S. that are not in compliance with air-quality standards. Oxygenated gasoline contains ethers or alcohols to reduce emissions of carbon monoxide. Oxygenated gasoline must be used during the cold months of the year in certain areas of the country that are not in compliance for carbon monoxide. Conventional gasoline, which can be sold and used in all other areas, may contain ethers or alcohols. When 10% ethanol is added to conventional gasoline, it is known as gasohol. Appendix E is the executive summary of a comprehensive analysis of reformulated gasoline for New York State.

[2] Numbers in brackets indicate references listed at the end of this report.

in lower CO_2 emissions than with gasoline and diesel fuel. However, when the full fuel-cycle from resource through end-use is included and all other greenhouse gases are accounted for, some alternative fuels may increase total greenhouse gases depending on the production process used. (Appendix F explains more about greenhouse gas emissions.)

Alternative vehicle fuels such as natural gas, methanol, ethanol, propane, and electricity have long been proposed as a way to provide significant air quality benefits over petroleum fuels, including reformulated gasoline and "clean diesel fuel."[3] (See Appendix G for information about production and basic characteristics of these alternative fuels.) By the late 1980s, these alternative fuels had been demonstrated in several states, at the federal level, and by other countries, but the results were not conclusive.[4] Questions remained as to whether alternative-fuel vehicles (AFVs) could consistently and reliably achieve emission reductions, especially since many different types of engine technologies were being used, with apparently varying levels of success. It also remained unclear what potential cost, operational, or other disadvantages alternative fuels might produce that could offset air-quality benefits.

Alternative fuels also have been proposed as a means to increase U.S. energy security. The oil supply and price shocks of the 1970s highlighted the dangers of the nation's dependence on imported petroleum. Since that time, most energy-consuming sectors of the economy have successfully diversified their sources of energy to make them less vulnerable to future oil shocks. The transportation sector has been singularly unsuccessful in this regard. As in 1973, when the Arab oil embargo disrupted the fuel market in the U.S., the cars, trucks, and buses driven today are still almost totally dependent on petroleum. As current dependence on imported sources of petroleum heads towards an all-time high, the vulnerability of the transportation sector grows.

Recognizing this situation, the U.S. Congress passed the Energy Policy Act of 1992, known as EPACT (see Appendix H for a detailed explanation of EPACT). Some of the objectives of EPACT are to promote, to the maximum extent practicable, the replacement of petroleum fuels in the transportation sector with fuels that reduce oil imports, improve the health of the nation's economy, and reduce greenhouse gas emissions. To achieve these goals, EPACT requires federal, state, and fuel-provider fleet operators to acquire and use

---

[3] Clean diesel fuel is diesel fuel that has reduced sulfur and aromatic content. This results in reduced emission of particulates and nitrogen oxides.

[4] The majority of AFV demonstrations in the U.S. at that time had been conducted in California. California's climate and air pollution problems are distinctly different than those of New York State; moreover, the demonstrations in California did not collect emissions data and other information important to decision makers in other states.

AFVs. EPACT also includes provisions for requiring private and municipal fleet operators to acquire AFVs if deemed necessary by the U.S. Department of Energy to meet EPACT goals.

Since the early 1980s, NYSERDA has funded projects to evaluate the benefits of AFVs. In 1989, NYSERDA, under the guidance of the State's Alternative-Fuel Vehicle Coordinating Council,[5] greatly expanded the State's exploration of alternative fuels by initiating the AFV-FDP. The objective of the AFV-FDP was to place large numbers of AFVs in service in State, municipal, and private fleets to provide "real-world" answers to questions about their benefits.

Data and other information derived from the AFV-FDP are intended to assist State and local policy makers in determining the contribution alternative fuels can make towards achieving three major objectives:

- Improving air quality, especially in urban areas, and meeting National Ambient Air Quality Standards
- Diversifying the State's fuel supply mix by reducing the transportation sector's dependence on petroleum
- Creating growth opportunities for New York State companies that produce AFVs, vehicle components, and related infrastructure

The AFV-FDP has been a cooperative demonstration program that relies on the public and private sectors, as well as on national-state-local government partnerships, to demonstrate and evaluate alternative fuels and technologies. Program participants have included 21 fleets across the State operating a mix of 257 AFVs that logged 7.3 million miles through September 1995.

Program participants have included 21 fleets across the State operating a mix of 257 AFVs that have logged 7.3 million miles.

The AFV-FDP has generated a wide range of essential data unavailable elsewhere to characterize and compare AFV emissions, fuel consumption, performance, safety, and maintenance characteristics relative to conventional-fuel-vehicle counterparts. The vehicle

[5] The AFV Coordinating Council comprised representatives from NYSERDA, the New York State Thruway Authority, the New York City Department of Environmental Protection, the Port Authority of New York and New Jersey, and the following New York State agencies: Office of General Services, Department of Environmental Conservation, and Department of Transportation.

emissions data may help environmental agencies and others to simulate the benefits of various alternative-fuel use scenarios. Economic and energy data enable the evaluation of alternative-fuel substitutions as one of several elements in strategies to reduce petroleum demand and the State's dependence on imported oil.

The AFVs used in this demonstration have displaced about 114,000 gallons of gasoline and 748,000 gallons of diesel fuel (through September 1995) that would otherwise have been used. The majority of the AFV-FDP AFVs remain in operation, continuing to displace petroleum while reducing tailpipe emissions and displaying AFV hardware built in New York State.

Section 2

AFV-FDP METHODOLOGY

Building on a variety of smaller projects started in the 1980s, the AFV-FDP was officially launched in 1990 as a 5-year statewide demonstration that eventually entailed 257 cars, trucks, and buses operated by 21 fleet operators. The fleets that participated were predominately from State agencies or local governments (see Table 2.1). NYSERDA established a cooperative agreement with each of the participating fleet operators to share the costs of acquiring AFVs, purchasing fuels, establishing refueling facilities, and collecting vehicle performance and emissions data. This approach facilitated "buy-in" by the participating fleets and made the program more effective in achieving comprehensive data collection.

In many ways, State and local fleets represent an ideal laboratory for testing the implementation of AFVs. In these fleets, AFVs are both operated under controlled conditions that facilitate data collection and exposed to the entire range of driving conditions experienced by the public. State fleets also are among the first to come under the EPACT mandates to purchase AFVs, beginning in the 1997 vehicle model year (see Appendix H). These purchases of AFVs also may satisfy these fleets' obligations under the Clean Air Act Amendments of 1990 (CAAA) Clean Fuel Fleet mandate to purchase Clean Fuel Vehicles.[6] (See Appendix I for a detailed explanation of the requirements of the CAAA Clean Fuel Fleet program.) An additional benefit of using government fleets is that the data collected can be disseminated widely for the benefit of

Table 2.1 Fleet Operators Participating in the AFV-FDP

• NYS Thruway Authority	• Monroe County
• Port Authority of New York and New Jersey - John F. Kennedy Airport	• Yankee Trails Holiday Tours Bus Company
• Town of Tonawanda	• City of Buffalo
• Broome County Transit	• Erie County
• Central New York Regional Transportation Authority	• Kenmore-Tonawanda School District
• Long Island Bus	• NYS Dept. of Environmental Conservation
• Niagara Frontier Transit Authority	• NYS Public Service Commission
• NYC Office of Fleet Administration	• NYS Office of Mental Health, South Beach
• Rochester-Genesee Regional Transportation Authority	• US Postal Service - Staten Island
• NYSERDA	• NYS Office of Parks, Recreation and Historic Preservation
• City of White Plains	

[6] Clean Fuel Vehicles must use alternative fuels, reformulated gasoline, or clean diesel fuel (diesel fuel modified, by reducing sulfur content and other changes, to produce lower emissions). EPA determines what fuels are acceptable for use in Clean Fuel Vehicles.

all fleet operators, unlike private fleets, where competitive factors may limit publication of experimental findings.

The operators had full control over the AFVs in their fleets, including the options to stop using a vehicle or to switch back to conventional fuel. During the data-collection period (from 1992 through 1995), these options were used temporarily in several situations. In each case, NYSERDA worked with the fleet operators to resolve problems encountered with their AFVs, refueling facilities and garages, and operating staff. For example, some vehicles converted to compressed natural gas (CNG) bifuel (vehicles that can run on either CNG or gasoline) operation were found to have limited range when using CNG, and the operators found frequent switching back and forth between fuels troublesome. This deficiency was corrected by the installation of one additional CNG storage cylinder per vehicle. In another situation, one vehicle that had been converted from gasoline to dedicated CNG operation was believed to have inherent drivability problems caused by the CNG fuel system. A thorough analysis found a problem with the engine control computer unrelated in any way to the CNG fuel system, and the problem was corrected.

More nettlesome were problems with fuel leaks and fuel specifications. In several instances, CNG leaked from vehicle fuel systems and, although no injuries, fires, or property damage occurred, thorough investigations were required to determine the causes. Generally, the CNG leaks were due to fittings that required tightening, but two leaks were attributed to defective storage cylinders. As for fuel specifications, not all suppliers of alternative fuels are accustomed to meeting specifications for motor fuel (e.g., methanol is generally sold only for use as a solvent or chemical feedstock) and difficulties were encountered in meeting the desired specifications year-round. In the most notable example, the vapor pressure of the M85 fuel (blend containing 85% methanol and 15% gasoline) delivered to the Thruway Authority was too low and contributed to cold-start performance inferior to that using gasoline. One instance of M85 fuel contamination also occurred, but was corrected before any damage was done to the vehicles.

Table 2.2 shows the type of vehicles and fuels used in the AFV-FDP. Detailed data were collected from 209 of the 257 vehicles in the program. These 209 AFVs collectively traveled 7.3 million miles during the three-year data collection period, consuming the equivalent of 114,000 gallons of gasoline and 748,000 gallons of diesel fuel. Of the original 257 vehicles in the AFV-FDP, 227 are still in operation.[7]

---

[7] Five of the AFVs were operated to the ends of their useful lives. Twenty more had to be converted from methanol to gasoline operation because of an agreement with the vehicle manufacturer that supplied them (these were pre-production vehicles that could not be supported indefinitely in alternative fuel configuration). Three methanol transit buses were converted back to diesel fuel after their demonstrations. One propane vehicle was converted back to gasoline because it had insufficient range on propane. One CNG automobile was taken out of service due to a traffic accident unrelated to alternative fuel use.

Table 2.2 AFVs by Vehicle and Fuel Type

	CNG	Electric	Ethanol	Methanol	Propane	Totals	Percent
Light-Duty Trucks	46				5	51	19.8
Passenger Cars/Vans	29	1	1	89		120	46.7
Postal Vans	50					50	19.5
School Buses	2					2	0.8
Transit Buses	31			3		34	13.2
Totals	158	1	1	92	5	257	100
Percent	61.5	0.4	0.4	35.8	1.9	100	

Data regarding vehicle specifications, miles traveled, fuel use and costs, emissions, performance, and maintenance histories were collected and stored in a computer database. In all, 5,900 vehicle-months of data are included in the AFV-FDP database and are accessible to the public through NYSERDA.

Over the course of the AFV-FDP, 1,003 emissions tests were performed. The tests were performed on a chassis (treadmill-type) dynamometer, and tailpipe emissions were measured over a variety of simulated driving conditions such as congested stop-and-go driving and constant-speed highway driving. The objective of the emissions testing was not to determine how clean AFVs could be; rather, it was to find out how clean AFVs *would be* compared to conventional vehicles in regular use and maintained by conventional-fuel vehicle mechanics. The emissions test results were among the more revealing data sets collected by the AFV-FDP.[8]

The widespread adoption of alternative fuels has been stymied by a "chicken-and-egg" syndrome, with the vehicle manufacturers reluctant to build AFVs without a refueling infrastructure in place, and the fuel providers unwilling to invest in fuel production, distribution, storage, and dispensing infrastructure without a ready market of AFVs. Because of the general lack of AFV refueling infrastructure at the start of the

[8] All the emissions tests were chassis dynamometer tests. The light-duty vehicles were tested using the City and Highway portions of the Federal Test Procedure, and the New York City Cycle. The heavy-duty vehicles were tested using the "A" and "B" New York City Cycles and the Central Business District Cycle.

AFV-FDP in 1990, the project scope included assistance in establishing refueling stations to support field operations.

Through the AFV-FDP, nine methanol refueling facilities were established at convenient intervals along the length of the New York State Thruway to support vehicles operated by the Thruway Authority. This enabled the Thruway Authority's methanol vehicles to travel from New York City to Buffalo without having to travel a carefully planned route to avoid running out of fuel. In addition, a public methanol refueling facility was established in New York City, a methanol refueling facility was built to serve fleet vehicles in Monroe County, and both a methanol and an ethanol refueling facility were set up to serve municipal vehicles in White Plains. In cooperation with participating municipalities, gasoline service station operators, and gas utility companies, three CNG refueling facilities were established to serve municipal and commercial fleets and the general public. Also, a propane distributor supplied two refueling stations to support AFV-FDP vehicles operated at two State Parks.

One of the major challenges faced by the AFV-FDP was the rapid evolution of AFV technology. The program's approach generally was to use commercially available AFV equipment, so as to replicate the experience of typical AFV users, and to use a mix of standard-design and advanced-design components to gain an understanding of the costs and benefits of innovations that have become available in the marketplace. Also, in some cases, experimental or limited-edition prototype equipment was used to provide insight into the future direction of AFV technology.

The AFV-FDP has itself been a source of technical innovations, especially in the areas of refueling equipment and garage safety. Work done to establish refueling facilities and to resolve apparent fuel-quality problems and other field problems has helped improve equipment design, benefiting companies that build, install, and operate AFV refueling stations. Also, the AFV-FDP's work to assess the safety requirements of garages and maintenance facilities for AFVs has resulted in the development of guidelines to assist fleet operators and facility managers (see Appendix J).

The AFV-FDP has included efforts to educate fleet operators and the public about AFV costs, benefits, and operating characteristics. Presentations have been made directly to groups of fleet operators, as well as to numerous technical meetings and conferences. AFVs have been exhibited at auto shows around the State, and taken to schools and various community events. Findings from the AFV-FDP also have contributed to a growing national awareness of the need for vehicle storage and maintenance facility modifications tailored to AFV requirements, and have helped prompt the National Fire Protection Association to review its existing building codes and standards for garages to include AFV requirements.

The AFV-FDP's efforts have helped assist follow-on programs. For example, some of the same fleets that participated in the AFV-FDP also are participating in the U.S. Department of Energy Clean Cities program.[9] Their efforts range from simple public information campaigns to vehicle conversions and purchases to alternative-fuel infrastructure development, including establishment of alternative-fuel corridors linking cities. The country's leading automakers and fuel providers have approached these community programs with initiatives to provide them with AFVs and alternative-fuel infrastructure. Currently, there are four Clean Cities in New York State: White Plains, Western New York (Buffalo and surrounding communities), Central New York (Syracuse and surrounding communities), and Greater Long Island. Other Clean Cities groups are organizing in New York City, Rochester, Albany, and elsewhere.

[9] Clean Cities is a locally based government/industry partnership program coordinated by the U.S. Department of Energy to expand the use of alternatives to gasoline and diesel fuel. Clean Cities builds on local initiative, provides options to solve local problems, and creates partnerships as the mechanism to develop solutions to establish a sustainable, nationwide alternative fuels market.

Section 3

AFV-FDP FINDINGS

LIGHT-DUTY AFVs

Natural Gas

- *The AFV-FDP included 125 light-duty natural gas vehicles (passenger cars, pickup trucks, and vans; most were bifuel*[10] *gasoline and natural gas).*
- *These vehicles operated an average of 986 miles per month using the gasoline equivalent of 45.7 gallons per month of natural gas; natural gas was 42% of the total fuel used.*[11]
- *A total of 738 emissions tests were completed on natural gas, and another 225 emissions tests were completed by control vehicles on gasoline.*
- *The fleets that operated light-duty natural gas vehicles included: Town of Tonawanda, Monroe County, City of Buffalo, Erie County, NYS Dept. of Environmental Conservation, NYS Public Service Commission, NYS Office of Mental Health - South Beach, and the US Postal Service - Staten Island. (Figure 3.1 illustrates a few of the 50 CNG postal vans that participated in the AFV-FDP.)*

Physical Properties and Production. Natural gas is composed primarily of methane, with a small percentage of ethane and minute amounts of propane and heavier hydrocarbons typically present. Natural gas also can include small amounts of nitrogen, carbon dioxide (CO_2), and oxygen. Impurities can include water vapor, hydrogen sulfide, and entrained particulates. Table 3.1 lists typical properties for natural gas distributed in the State.

New York State gets its natural gas via pipelines fed primarily by gas wells in states such as Texas, Louisiana, Oklahoma, and Kansas. The State also receives natural gas from Canada (some of which originates in the U.S.), and produces some indigenous natural gas from small pockets located mostly in the western part of the State. These indigenous sources are difficult to develop economically compared to the large natural gas fields in the major natural-gas-producing states.

---

[10] "Bifuel" refers to those vehicles with two fuel systems, in this case gasoline and natural gas. Only one fuel system can be used at one time. "Dedicated" refers to vehicles with one fuel system, such as gasoline vehicles that have been converted to operate only on natural gas by removing their gasoline fuel systems and replacing them with natural gas fuel systems.

[11] The bifuel vehicles used gasoline because CNG refueling facilities were not always available where the vehicles traveled and because the CNG refueling facilities were not always operational.

Figure 3.1 U.S. Postal Service CNG Vans on Staten Island

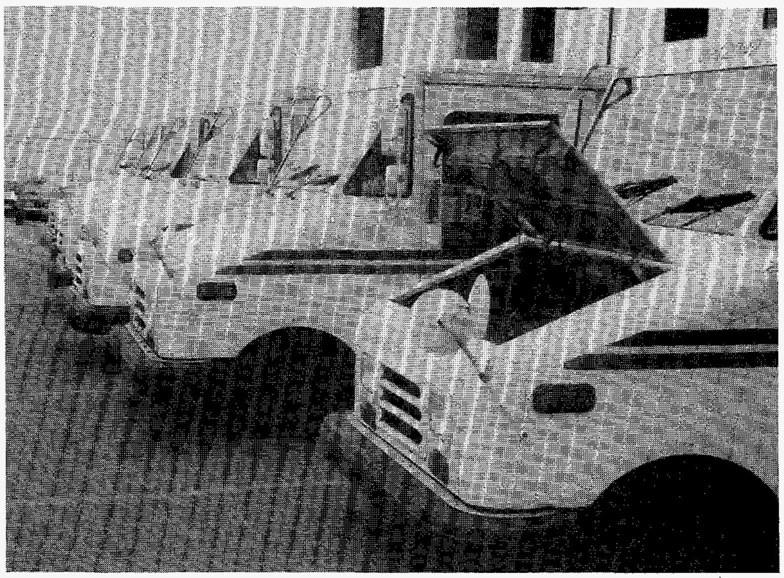


Table 3.1 Comparison of Typical Natural Gas and Gasoline Properties

Fuel Property	Natural Gas[1]	Gasoline[2]
Molecular Weight	16	100 to 105
Methane Content, Percent	95 to 97[3]	0
Composition, Weight % Carbon Hydrogen Oxygen	 75 25 0	 85 to 88 12 to 15 0 to 4
Weight, lb/gal	5.1 to 5.8[4]	6.0 to 6.5
Boiling Point, °F	-260	80-437
Lower Heating Value, Btu	925-950/scf[3]	109,000-119,000 per gallon
Octane Rating, (R+M)/2	130	87-93
Autoignition Temperature, °F	1,004	495

[1] Assumes pure methane, except where noted
[2] Nominal, varies with grade and composition of gasoline
[3] Typical values for natural gas in New York State
[4] Range of values typical for natural gas in New York State. The National Conference on Weights and Measures has proposed an equivalence of 5.66 pounds chosen to represent the amount of natural gas that would take a vehicle as far as one gallon of gasoline would.

Energy Storage Density and Storage Cost. Based on discussions with AFV-FDP fleet operators (see Appendix K), reduced vehicle operating range is CNG's greatest physical drawback, a factor that stems from CNG's low energy storage density (i.e., the amount of energy in a unit volume of natural gas is much less than in the same volume of gasoline). For vehicle use, the same natural gas that is distributed at very low pressures for heating and cooking is compressed and stored as CNG in specially designed tanks at pressures of 2,400 to 3,600 pounds per square inch (psi). Figure 3.2 illustrates the difference in energy storage density for CNG versus gasoline. Besides needing three to five times the volume for storage, CNG storage cylinders are much heavier than gasoline tanks and are more difficult to place within the vehicle because of their cylindrical shape.

To reduce the weight of CNG tanks, manufacturers in recent years have introduced lighter materials. To store the CNG equivalent of 10 gallons of gasoline, steel-reinforced (steel wrapped with Kevlar® or similar high-strength reinforcing bands) CNG cylinders would weigh about 260 pounds, aluminum-reinforced CNG cylinders would weigh about 220 pounds, and all-composite (made from combinations of carbon fiber and other advanced materials) cylinders would weigh about 110 pounds. (Figure 3.3 illustrates the typical difference in CNG cylinder weight with type of material.) The cost of steel-reinforced cylinders to store the equivalent of 10 gallons of gasoline would be about $1,000, versus about $1,500 for aluminum-reinforced cylinders, and all-composite cylinders would cost about $1,250 (see Figure 3.4). Figure 3.5 shows how a 2-cylinder CNG fuel system was installed in Department of Environmental Conservation (DEC) Ford pickup trucks.

By comparison, the empty weight of a 10-gallon gasoline tank is only 20 to 30 pounds (depending on the shape of the tank and the material used), and its cost is relatively very low.

CNG Vehicle Fuel Systems. Just as tanks have evolved, natural gas fuel systems have evolved tremendously over the past few years as the popularity of natural gas vehicles has grown. The oldest-style natural gas fuel systems reduce the pressure of the gas coming from the CNG tanks and employ simple mechanical mechanisms to mix the natural gas with the air entering the engine. This type of fuel system operates without electronic controls and is known as an "open-loop" system because it does not monitor the oxygen content of the exhaust gases to adjust the ratio of fuel to air entering the engine. Second-generation CNG fuel systems incorporate an oxygen sensor in the engine exhaust to adjust the ratio of fuel to air entering the engine and are known as "closed-loop" systems. The most advanced CNG fuel system technology, as found in dedicated CNG vehicles built by vehicle manufacturers, is essentially the same as the prevalent multipoint fuel injection systems found in almost all new gasoline vehicles. The primary difference is that the injectors are optimized to use natural gas instead of gasoline.

Figure 3.2 Volume Needed to Store Equal Amounts of Energy, CNG Compared to Gasoline (Fuel Only, No Hardware)

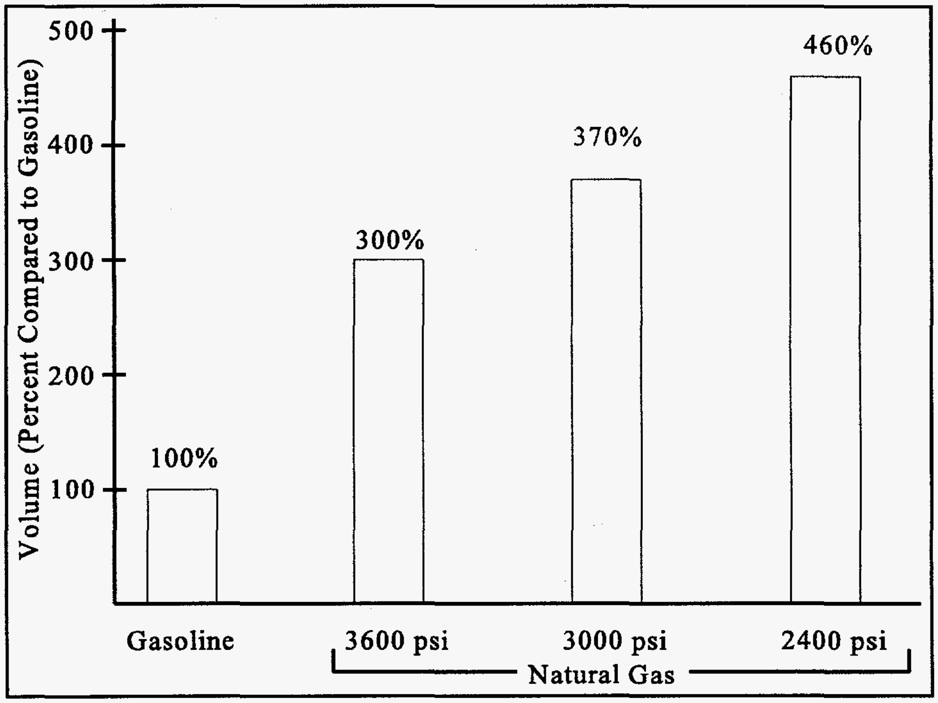


Figure 3.3 Typical CNG Cylinder Weights Per Gallon Storage Volume (3,600 psi Cylinders)

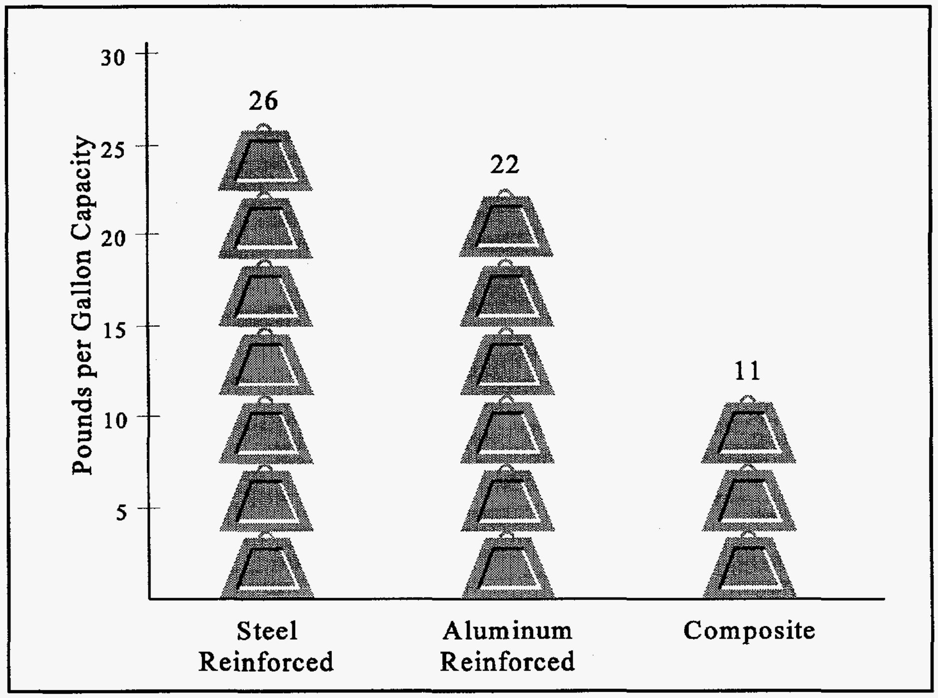
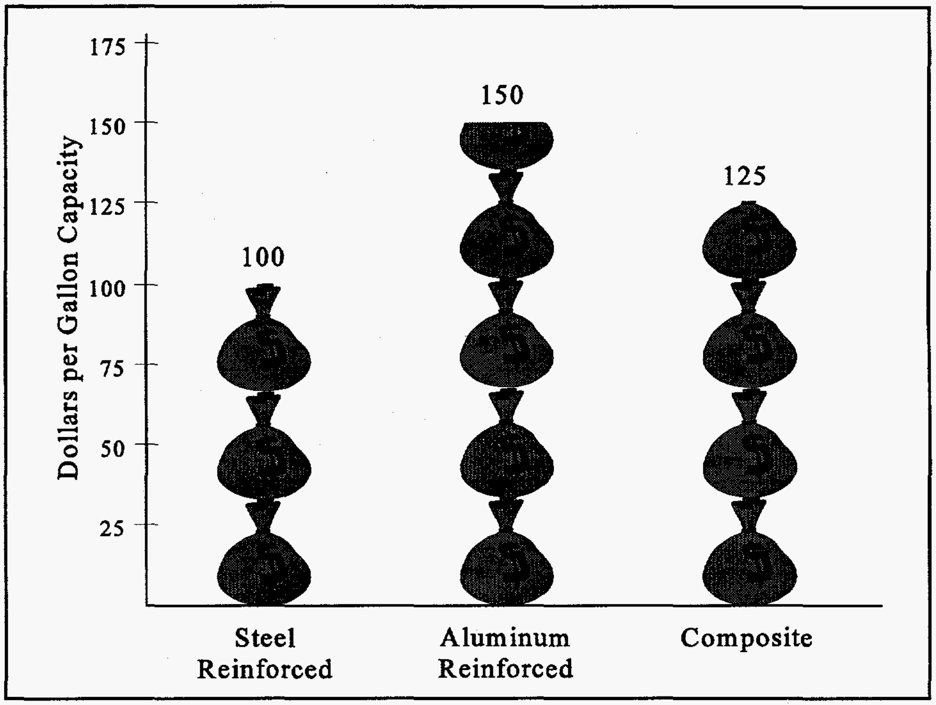


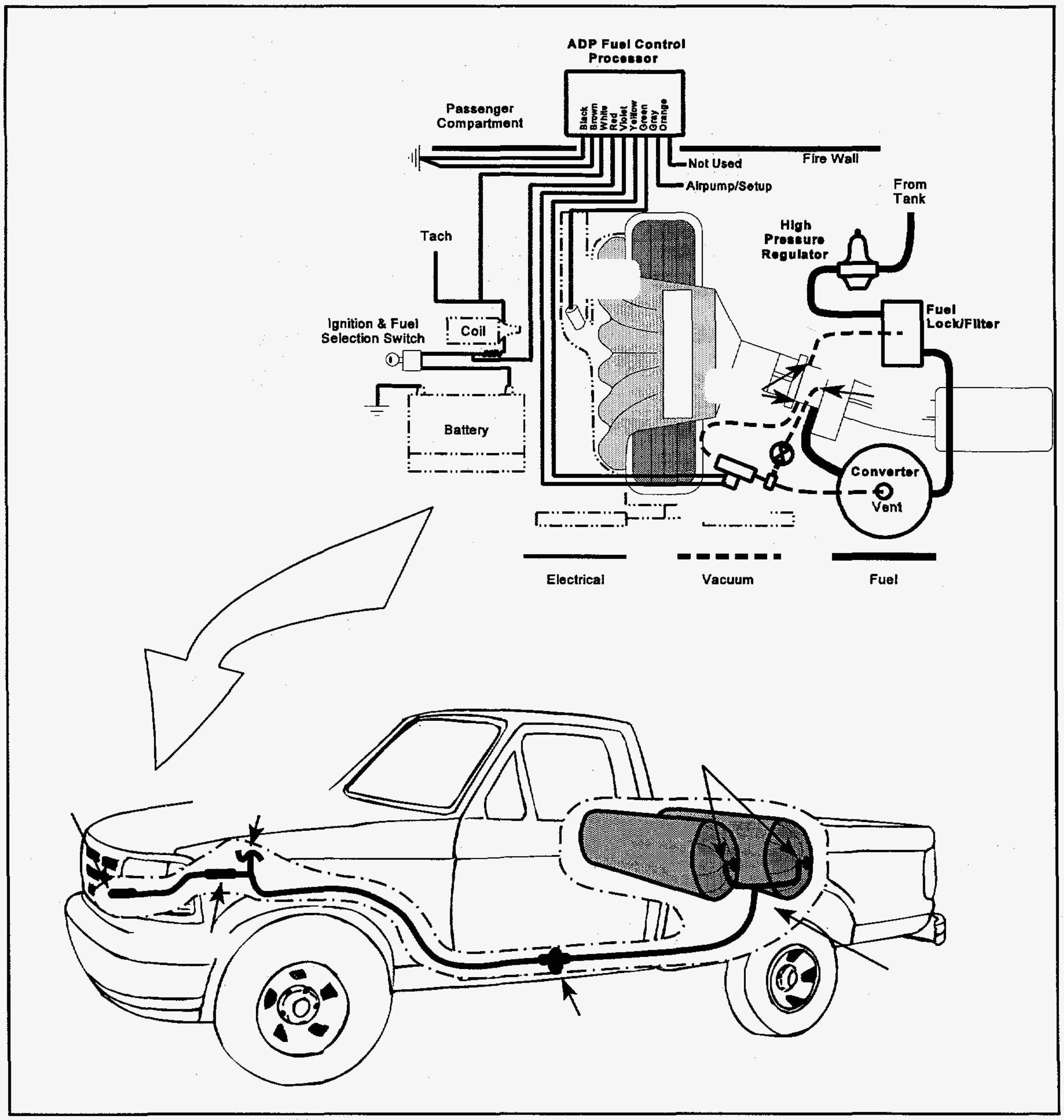
Figure 3.4 Typical CNG Cylinder Cost Per Gallon Capacity (3,600 psi Cylinders)



Most CNG fuel systems currently in service were designed to be installed on a gasoline vehicle while retaining the gasoline fuel system. This bifuel approach allows the driver to change from one fuel to the other by flipping a switch (the vehicle can only use one fuel at a time), or the vehicle can be set up to switch automatically to gasoline when the CNG is depleted. Bifuel configurations were adopted for two reasons: (1) the difficulty of incorporating enough CNG fuel storage to equal the operating range on gasoline; and (2) the scarcity of places to refuel with CNG, other than the home base of the vehicle. Auto manufacturers recognize that bifuel CNG vehicles can play an important role in creating demand for CNG refueling infrastructure, and have decided to assist by offering vehicles especially configured to become bifuel vehicles. The only difference in these vehicles is that a few engine modifications have been made in the interests of engine durability when using natural gas, and a smaller gasoline fuel tank is usually installed, creating more room for CNG cylinders.

Open-loop CNG fuel systems added to vehicles vary significantly in performance and emissions because they have limited capability to adjust to all the operating modes of the vehicle, and because it is very difficult to set these systems up properly in the field. For example, the AFV-FDP found wide variation in emissions from vehicle to vehicle using open-loop CNG fuel systems. Somewhat lower variability was found with closed-loop CNG fuel systems. Newer CNG fuel systems make more use of existing gasoline

Figure 3.5 Typical CNG Fuel System Pickup Truck Installation



fuel system sensors and controls, and thus are better able to adjust to vehicle operation and reduce performance and emissions variability. All but a few of the CNG fuel systems on the AFV-FDP's light-duty vehicles were installed in the field (i.e., at conversion shops). Factory-installed CNG fuel systems in both bifuel and dedicated CNG vehicles are inherently better integrated with the engine, fuel, and emissions systems, and consistently provide very low emissions.

> Natural gas fuel systems have evolved tremendously over the past few years...

Vehicle Power, Acceleration, and Drivability. Natural gas displaces some of the air that otherwise would enter the engine and has a slightly lower flame speed; these factors reduce the power of engines using CNG vs. gasoline [2]. Bifuel vehicles typically have about a 10% power loss when operating on CNG, even after advancing the spark timing to compensate for slower flame speed and to take advantage of the higher octane of natural gas. Dedicated CNG vehicles can take additional advantage of the high octane of natural gas by increasing the compression ratio of the engine. (Ford increased the compression ratio of the CNG Crown Victoria 4.6-liter V-8 engine to 10:1, as compared to 9:1 for the gasoline version of the engine.) This not only increases power, but increases efficiency as well.

However, even dedicated CNG vehicles are at a disadvantage when compared to similar gasoline vehicles because the CNG fuel cylinders weigh more than the typical gasoline fuel tank. Table 3.2 shows the compression ratio, acceleration, and fuel economy for the CNG vehicles in the South Beach Psychiatric Center AFV-FDP fleet. The CNG vehicles included a 1994 OEM[12] Dodge CNG Ram Van, a 1990 Dodge van converted to dedicated CNG operation (i.e., the gasoline tank and fuel system were removed), and a 1989 gasoline Dodge van used as a control vehicle. While the OEM Dodge CNG van did not have an increased compression ratio, it still had faster acceleration and higher fuel economy than the converted van. The reason for these differences presumably is that the OEM engine and fuel system were more completely optimized for using CNG.

The drivability (hesitation, smoothness, stalls, etc.) of bifuel vehicles is often judged by users to be less satisfactory on CNG than on gasoline. Users were surveyed in the AFV-FDP to document drivability and other user perceptions (Appendix K). Cold-start problems were observed with bifuel CNG vehicles, presumably because the systems have difficulty metering natural gas accurately enough during the very

---

[12] Original Equipment Manufacturer—when an AFV is referred to as an "OEM" it was designed and built as an AFV by a vehicle manufacturer, as compared to vehicles converted by others to use alternative fuels.

Table 3.2 Comparison of OEM and Converted Dedicated CNG Dodge Vans

	Engine	Compression Ratio	Acceleration to 60 mph, seconds	Fuel Economy, mpg[1]
1994 OEM CNG Van	5.2L-V8	9.1	12.9	10.5
1990 CNG Converted Van	5.2L-V8	9.2	19.9	9.8
1989 Gasoline Control Van	5.9L-V8	8.1	12.5	8.5

[1] Measured from on-road operation of the vehicles in typical service.

low fuel-flow rates typical of engine starts. Dedicated CNG vehicles fared better, with drivability judged by users to be superior to bifuel vehicles and essentially the same as comparable gasoline vehicles. In the AFV-FDP, drivability problems with CNG bifuel vehicles discouraged some drivers from using CNG. Many of these problems were found to be an indication that the CNG fuel system was not properly tuned.

Fuel Efficiency. The AFV-FDP's bifuel vehicles used from 2 to 12% more fuel (on an energy basis) on CNG than on gasoline. The fuel efficiency of the dedicated OEM CNG vehicle did not differ significantly from the similar gasoline control vehicle. The ratio of fuel efficiency between CNG and gasoline operation varies because gasoline's heating value changes according to its oxygen content, which itself varies by region (reformulated gasoline contains more oxygenates and is required in certain areas of New York State) and time of year (oxygenated fuel programs to reduce carbon monoxide emissions during the winter months often require higher oxygenate levels than in either normal or reformulated gasoline). However, these fuel changes should affect vehicle fuel efficiency by only a few percentage points. Based on AFV-FDP data, bifuel vehicles using CNG are likely to use slightly more fuel than when using gasoline and OEM CNG vehicles are expected to have the same fuel efficiency as similar gasoline vehicles.

Fuel Costs. In most cases, the cost of an equivalent amount of CNG is less than gasoline, resulting in lower fuel operating costs. The cost of CNG in New York State varies according to utility service area. Prices, including road-use, excise, and sales taxes, typically range between the price of regular-grade gasoline and as much as 25 cents per gallon less.[13] Table 3.3 lists the miles a vehicle would have to travel

[13] Natural gas has an octane value higher than that of any premium gasoline, which could allow engine designs more efficient than gasoline engines. However, to date auto manufacturers have taken only very limited steps to optimize their dedicated natural gas engines to achieve significant efficiency advantages compared to gasoline engines. If natural gas engines are developed that are optimized for maximum efficiency, the price of CNG should more appropriately be compared with the price of premium gasoline.

to achieve a three-year simple payback of a typical CNG fuel system costing $4,500 (or a CNG vehicle with an incremental cost of $4,500) for various vehicle fuel economies and fuel-price differentials. For example, a vehicle with a fuel economy of 15 miles per gallon (mpg) would have to travel 90,000 miles per year to achieve three-year simple payback, if CNG were priced 25 cents per gallon lower than gasoline. As Table 3.3 indicates, only a vehicle that uses large quantities of fuel, either because the vehicle has low fuel economy, high annual mileage, or both, is a good candidate for CNG if the vehicle owner is trying to accomplish a three-year simple payback. As the price of CNG fuel systems change, the numbers in Table 3.3 would change correspondingly (e.g., if CNG fuel system prices were cut in half, it would take half the miles to achieve a three-year simple payback). Also, if the price of CNG drops with increased infrastructure growth, the CNG price differential could increase beyond the range shown in Table 3.3, leading to improved CNG economics.

Other Operating and Maintenance Costs. Aside from fuel and capital costs, other important cost issues include operation and maintenance costs (O&M, measured separate of fuel costs) and overall equipment durability. Gasoline and diesel fuel tend to have higher levels of sulfur and other undesirable trace constituents, as compared to CNG, and have greater potential to interact negatively with an engine's lubricating oil. Proponents of CNG point out that this fuel, compared to gasoline, tends both to leave engines free of deposits and greatly slow the rate at which lubricating oil degrades. For these reasons, one might expect that an engine would have a longer life and require fewer repairs and oil changes if it used CNG instead of gasoline.

On the other hand, vehicle manufacturers incorporate hardened valve seats and other upgraded components in the engines of their dedicated CNG vehicles to counteract the higher exhaust temperatures and lower

Table 3.3 Annual Miles Traveled to Achieve Three-Year Simple Payback of a CNG Fuel System[1] at Various Fuel Economies and Equivalent Gallon CNG Price Differentials

CNG Price Differential, $/Gallon	Vehicle Fuel Economy, Miles per Gallon			
	5	10	15	20
$0.35	21,429	42,857	64,286	85,714
$0.30	25,000	50,000	75,000	100,000
$0.25	30,000	60,000	90,000	120,000
$0.20	37,500	75,000	112,500	150,000
$0.15	50,000	100,000	150,000	200,000

[1] $4,500 installed fuel system price or vehicle incremental cost

lubricity associated with using CNG, suggesting that unmodified gasoline engines may be less durable when using CNG. Sufficient data are not available to determine conclusively the O&M and durability characteristics of light-duty CNG vehicles (bifuel or dedicated), compared to gasoline counterparts, except to say that bifuel vehicles equipped with standard gasoline engines accumulated many miles on CNG in the AFV-FDP, with no detrimental effects noted. The Town of Tonawanda, for instance, accumulated extensive data documenting its success at reducing the number of oil changes on its dedicated CNG conversion vehicles without any apparent adverse effects on engine life.

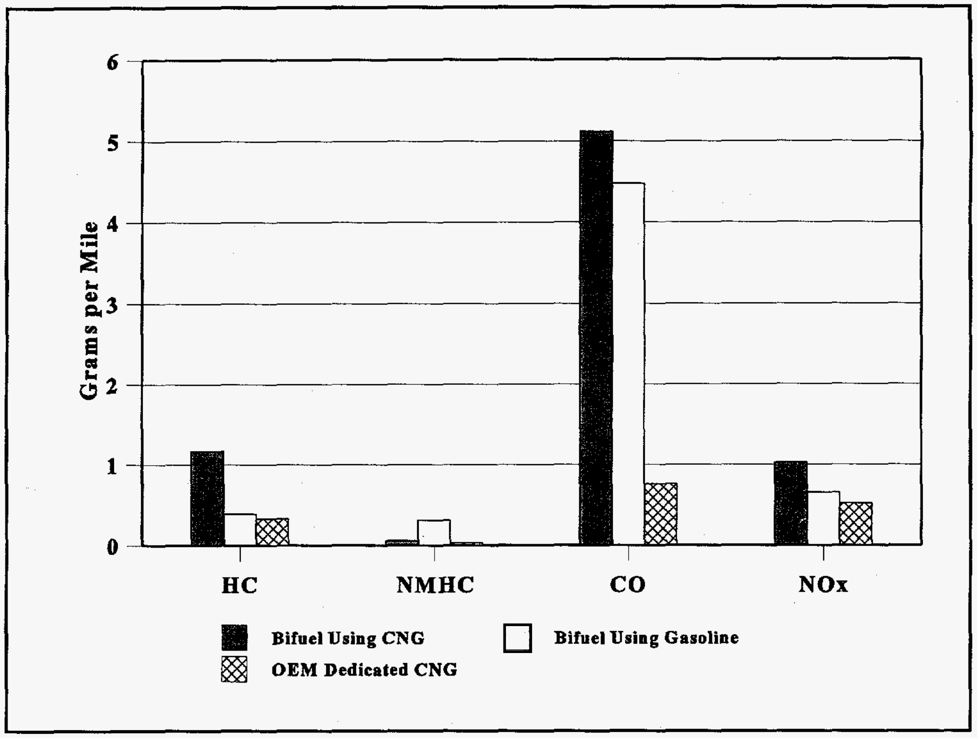
Emissions. The fact that natural gas is made up mostly of methane and, unlike gasoline, is sealed in a pressure-tight fuel system means that natural gas as a transportation fuel has several inherent emissions advantages. First, methane is less reactive in the atmosphere, which means that any fuel not burned in the combustion process does not participate significantly in the reactions that form ozone. Combined with the facts that dedicated CNG vehicles do not have evaporative, running loss, or refueling emissions (see Appendix C), this makes the use of natural gas very advantageous with respect to reactive hydrocarbons. By the same token, natural gas has very low toxic emissions compared to gasoline because it contains no benzene or other aromatic hydrocarbons. Carbon monoxide (CO) emissions from CNG vehicles also are typically lower (in properly tuned systems) because natural gas is fully vaporized when it enters the engine and, relative to gasoline, less fuel enrichment is needed for cold-start and acceleration. Oxides of nitrogen (NO_x) emissions also can be very low in CNG vehicles with well-controlled, three-way[14] catalyst emissions systems. These characteristics are typical of bifuel CNG fuel systems that have been integrated properly with the gasoline fuel and emissions-control systems; if poorly integrated, emissions increases can occur.

CNG exhaust emissions have low ozone-forming potential, and CNG can eliminate evaporative and other emissions.

Figure 3.6 illustrates the average tailpipe emissions (Federal Test Procedure) of both bifuel (CNG and gasoline) and OEM dedicated CNG vehicles that participated in the AFV-FDP. The bifuel data include tests of a wide assortment of CNG conversion systems, some of which performed poorly in emissions tests. The OEM dedicated CNG vehicles demonstrated the lowest emissions across the board. This performance

[14] Three-way catalysts oxidize hydrocarbons and carbon monoxide while simultaneously reducing oxides of nitrogen. A closed-loop fuel system is needed to make three-way catalysts work properly.

Figure 3.6 Light-Duty CNG Vehicle Exhaust Emissions



by dedicated CNG vehicles is even more impressive considering that these vehicles, unlike gasoline vehicles and the gasoline systems on bifuel CNG vehicles, do not produce evaporative, running loss, or refueling emissions. For the bifuel vehicles, CNG did not provide across-the-board tailpipe emissions reductions compared to gasoline. Total hydrocarbons (HC) were higher when using CNG since methane is more difficult to oxidize in catalytic converters than typical gasoline hydrocarbons. Non-methane hydrocarbon (NMHC) emissions when using CNG were much lower than when using gasoline, but CO and NO_x emissions were higher.

After adjusting for how emissions react in the atmosphere to form ozone, the ozone-forming potential of CNG vehicle exhaust is estimated to be only about half that of gasoline vehicle exhaust. In addition, evaporative, running loss, and refueling emissions of late-model gasoline vehicles are estimated to be nearly 50% higher than their exhaust hydrocarbon emissions.[15] Dedicated CNG vehicles thus should have overall ozone-forming potential that is 80 to 85% lower than gasoline vehicles. Bifuel vehicles should

[15] Evaporative emissions, and running and refueling losses for late-model gasoline vehicles were estimated using the EPA MOBILE5a model.

have from one-half to three-quarters of the ozone-forming potential of gasoline vehicles because the gasoline carried by bifuel vehicles causes evaporative, running loss, and refueling emissions.

Bifuel vehicles with open-loop CNG fuel systems tend to have poor NO_x emission characteristics because they do not maintain the proper air/fuel ratio for the three-way catalyst to effectively reduce NO_x emissions. Both CO and NO_x emissions from bifuel vehicles using CNG could be improved through periodic adjustment of the fuel system. This situation is characteristic of CNG fuel systems that have been installed in the field without the benefit of verification on a chassis dynamometer, in which case bifuel vehicles operating on natural gas will usually have higher NO_x emissions than when operating on gasoline. Bifuel vehicles with closed-loop CNG fuel systems do better, but significant improvements over gasoline are not typical. However, OEM dedicated CNG vehicles have been able to meet the California Ultra Low Emissions Vehicle (ULEV) emissions standards, the most stringent in the U.S. for light-duty vehicles. Table 3.4 lists the ULEV emissions standards and the CNG vehicles that to date have been certified to those standards. (Several other CNG vehicles have demonstrated the capability to meet ULEV standards but have not been certified.)

Based on the wide variation in emissions observed for bifuel CNG vehicles, it is difficult to generalize about the emissions benefits for any given vehicle. Fleet managers hoping to use bifuel CNG vehicles to achieve emissions reductions should use emissions tests to verify that field-installed CNG systems are providing the desired emissions reductions.

Greenhouse Gases. Vehicles using natural gas have an inherent advantage in CO_2 emissions compared to vehicles using gasoline. This is because natural gas contains more hydrogen and less carbon than gasoline. For vehicles of equal fuel efficiency, natural gas produces only about 75% of the CO_2 emissions. (This advantage is reduced in bifuel vehicles where CNG fuel efficiency is lower than that of gasoline.) When the entire fuel cycle from resource through combustion (full fuel cycle) is taken into account, along with

Table 3.4 ULEV Emissions Regulations

Emission	NMHC[1]	CO	NO_x
gm/mi	0.04	1.7	0.2

[1] Non-methane hydrocarbons

1996 Model Year Vehicles Certified to ULEV

- Ford CNG Crown Victoria
- Chrysler CNG Minivan

the other greenhouse gases, a dedicated CNG vehicle has an overall estimated greenhouse gas impact that is up to 15% less than that of a similar gasoline vehicle [3][4].

Refueling Infrastructure. Because of the limited operating range of CNG vehicles compared to gasoline vehicles, the development of a CNG refueling infrastructure is very important to future CNG vehicle implementation and acceptance. One of the highest hurdles to developing this infrastructure is the high cost of CNG compressors and other refueling equipment. Establishing a CNG refueling facility is significantly more expensive than establishing a typical gasoline refueling station.

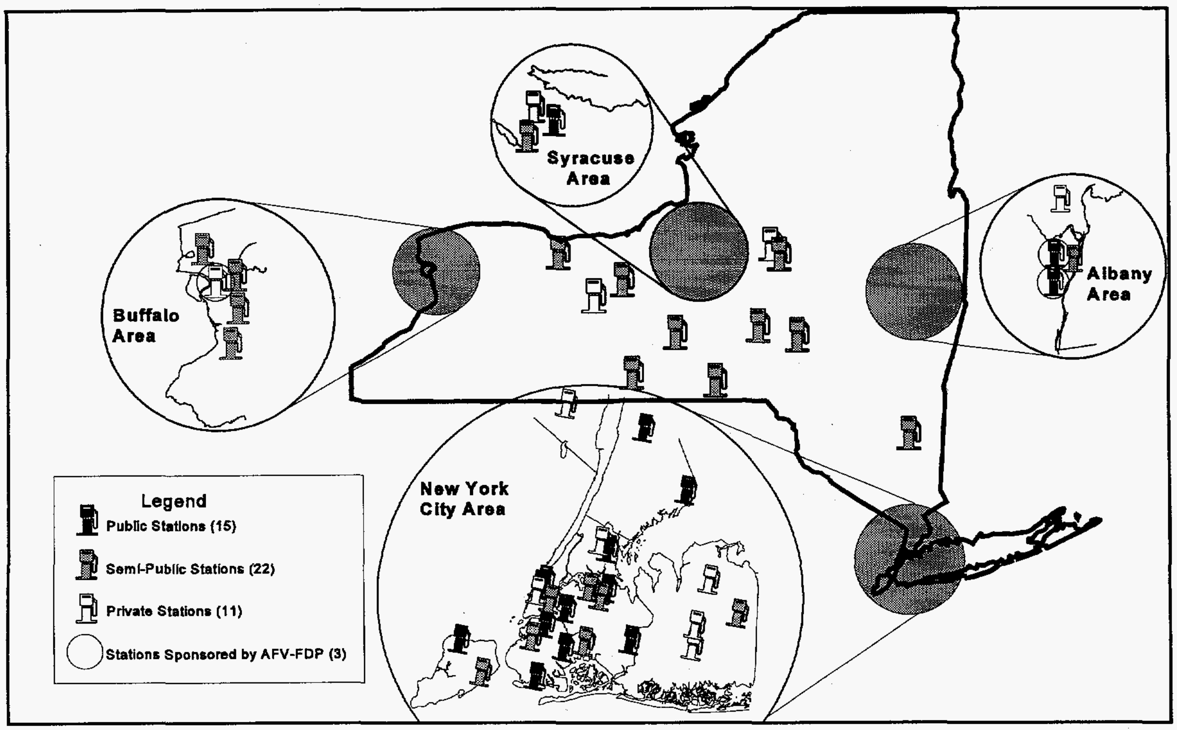
The high cost of CNG refueling facilities, along with the relatively small number of CNG vehicles on the road, has discouraged retailers from offering CNG in New York State. The State's natural gas utilities have taken the lead in establishing CNG refueling facilities. Figure 3.7 illustrates the location of the 47 currently known CNG refueling facilities in the State, virtually all of which are wholly or partially funded by gas utilities. This compares to approximately 6,000 gasoline stations in the State.

To facilitate operation of CNG vehicles in the AFV-FDP, the program helped establish CNG stations in Tonawanda, Colonie, and Glenmont, and has provided technical assistance for a planned station at the State University of New York at Buffalo.

Until CNG refueling facilities are widely distributed, CNG will tend to remain an alternative fuel best suited to fleet vehicles that stay within a limited geographical area, served by a few centrally located CNG refueling facilities.

Garage Safety Modifications. Storing and maintaining CNG vehicles inside buildings designed for gasoline and diesel-fuel vehicles presents safety hazards that need to be addressed. The primary concern is that natural gas may leak from a vehicle and accumulate near the building's ceiling in sufficient concentration to form a dangerous flammable mixture. Remedies to prevent a resulting fire or explosion have been proposed, and the National Fire Protection Association (one of the primary building code organizations) is currently debating changes to its garage codes to address CNG vehicles. Within a few years, updated codes should facilitate the adoption of CNG vehicles in those areas where uncertainty about building safety exists. In the interim, NYSERDA has produced a brochure, based upon AFV-FDP experiences, to inform fleet managers about the potential hazards of storing and maintaining AFVs in facilities designed for gasoline and diesel vehicles (see Appendix J and Volume 3).

Figure 3.7 CNG Refueling Facilities in New York State



The AFV-FDP provided site-safety inspections to help participating fleet operators prepare their facilities for CNG vehicles. As an example, the garage at South Beach Psychiatric Center was modified in accordance with the results of a site-safety inspection. This garage includes four bays for vehicle maintenance and covers a total of 4,000 square feet. The modifications included upgrading the electrical wiring in the ceiling to meet National Electrical Code Class 1, Division 2 specifications (areas where natural gas will only be present infrequently), installing a methane-detection system, and installing an improved ventilation system tied to the methane-detection system. The total cost was $35,000. Experience at other sites indicates that safety modifications may cost more or less depending on facility configuration, size, and present electrical and ventilation systems. In some cases, no modifications may be required. Whenever CNG vehicles are introduced to a facility, a fire safety expert or qualified professional engineer should perform a thorough analysis and provide recommendations for facility modification.

Bridge and Tunnel Prohibitions. Traditionally, the Port Authority of New York and New Jersey and the Triboro Bridge and Tunnel Authority prohibited natural gas vehicles from using the bridges and tunnels in New York City. NYSERDA, along with Brooklyn Union and Consolidated Edison, funded a study that estimated the hazard of natural gas vehicles in tunnels to be lower than that of gasoline vehicles [5]. Using this study and other information, these prohibitions have been lifted, removing a barrier to natural gas vehicle implementation in New York City.

Other Safety Issues. Because of the high pressures in CNG systems, concern is often expressed about the potential for leaks, fires, or catastrophic failure of storage tanks. Isolated instances of CNG fires and tank failures have been reported outside the AFV-FDP, and have usually been attributed to external abuse of the tanks or other human error, similar to circumstances surrounding fuel-system fires and other problems in gasoline vehicles. Participants in the AFV-FDP were provided training to ensure safe operation and handling of vehicles and refueling equipment. Safety incidents with light-duty CNG vehicles in the AFV-FDP were limited to a few leaks that did not cause any injury, fires, or property damage. One occurrence involved a slow leak from a valve on a CNG cylinder mounted behind the rear seat of a State Department of Environmental Conservation (DEC) sport-utility vehicle. The leak was caused by a loose fitting of a type that has been superseded by improved designs. Although the leak was fixed quickly, DEC elected to discontinue using CNG vehicles in which any part of the fuel system was inside the vehicle body. On two other occasions, the composite tanks used in two of Monroe County's bifuel passenger cars appear to have developed slow leaks. The manufacturer is working to diagnose the problem and reports that only one other similar leak has occurred with this type of cylinder, which is sold nationwide. Lastly, one of the State Public Service Commission's CNG vehicles leaked as a result of a fitting loosened by the impact of a traffic accident. The driver turned off the fuel shut-off valve, stopping the leak, as he was trained to do. This incident led to improvements in recommended practice for fuel component mounting.

NYSERDA, along with Brooklyn Union and Consolidated Edison, funded a study of the safety of bifuel vehicles [6]. The analysis assessed the relative hazard of vehicles containing both CNG and gasoline, compared to the hazard of a dedicated CNG vehicle. The study concluded that a bifuel vehicle poses a slightly greater risk than a dedicated CNG vehicle; however, this marginal increase in risk is small and is within the bounds of risk posed by gasoline-powered vehicles.

Summary. Table 3.5 summarizes the relative attributes of CNG and gasoline vehicles. Compared to gasoline, natural gas has up to 15% lower overall greenhouse gas emission impact. CNG's most significant beneficial impact on tailpipe emissions is in the form of reduced NMHC, and substantial additional benefits stem from elimination (on dedicated CNG vehicles) of evaporative, running loss, and refueling emissions. CNG fuel systems have evolved very rapidly and newer designs generally provide lower emissions and better performance.

The most significant physical drawback to dedicated CNG vehicles is reduced driving range. Bifuel vehicles overcome this limitation but entail compromises; dedicated CNG vehicles can generally match gasoline vehicles in acceleration, drivability, and fuel economy, whereas many bifuel conversions fall slightly short in these categories and do not provide nearly as much environmental benefit. Despite these compromises, bifuel conversions may play a crucial role in establishing CNG in the highway fuels market.

Table 3.5 CNG Vehicle Attributes Relative to Gasoline Vehicles

	Bifuel Conversion	Dedicated OEM
Range	Longer[1]	Shorter
Acceleration	Slower	Same
Drivability	Acceptable	Same
Fuel Economy (Energy Basis)	Lower	Same
Exhaust Emissions	Same[2]	Lower
Refueling, Evaporative and Running Loss Emissions	Slightly Lower	Much Lower
Ozone-Forming Emissions	Slightly Lower	Much Lower
Greenhouse Gases	Lower	Lower
Incremental Vehicle Price[3]	$3,500 to $5,000	$3,500 to $5,000

[1] Using both fuels

[2] Depends on vehicle tune

[3] Price of conversion or incremental price of OEM vehicle; typical range for most applications.

By overcoming vehicle operator's objections to range limitations and the scarcity of CNG refueling stations, bifuel conversions can enter the market more easily and their presence would provide incentive for fuel providers to make the large investments necessary to build CNG infrastructure, which in turn would knock down a significant barrier to dedicated CNG vehicles.

CNG vehicles cost significantly more than gasoline vehicles and this makes CNG more suitable for vehicles that are driven a large number of miles per year. High annual mileage, combined with the low per-gallon price of CNG, can create sufficient fuel cost savings to enable vehicle owners to recover their investment in a reasonable amount of time. Buildings used to park or maintain CNG vehicles should be evaluated by a professional engineer to determine whether changes to electrical and other systems are recommended to establish a safe working environment. With appropriate training, equipment and adherence to safety procedures, the overall risk of safety problems with CNG is estimated to be no greater than the risk with gasoline.

Methanol and Ethanol

- *The AFV-FDP included 89 light-duty methanol vehicles (all passenger cars) and one ethanol vehicle (passenger car); all the vehicles were flexible-fuel vehicles (FFVs).*

- *The methanol vehicles operated an average of 1,072 miles per month, using the gasoline equivalent of 22.1 gallons per month of methanol; methanol was 39% of the total fuel used.[16] The ethanol vehicle operated 190 miles per month and used the gasoline equivalent of 5.1 gallons per month of ethanol, which was 45% of the total fuel used by that vehicle.*

- *A total of 116 emissions tests were completed on the methanol vehicles, 12 on the ethanol vehicle, and 12 on control vehicles using gasoline.*

- *The fleets that operated methanol vehicles included the New York State Thruway Authority, the New York City Office of Fleet Administration, the City of White Plains, Monroe County, and NYSERDA. (Figure 3.8 shows a Thruway methanol vehicle and refueling facility.)*

Physical Properties and Production. Methanol and ethanol are clear liquid alcohols with low volatility and faint odors. Unlike gasoline, which contains a wide assortment of hydrocarbon molecule types, both methanol and ethanol are single-molecule liquids (e.g., a tank of methanol is full of identical molecules). Table 3.6 compares the properties of gasoline with methanol and ethanol.

As Table 3.6 illustrates, gasoline is composed of relatively high-molecular-weight hydrocarbons compared to methanol and ethanol. Gasoline has a wide, continuous boiling range while methanol and ethanol have single boiling points in the middle of the gasoline boiling-point range. Gasoline is much more volatile than methanol and ethanol have single boiling points in the middle of the gasoline boiling-point range. Gasoline is much more volatile than methanol or ethanol, in part due to the low-boiling-point compounds it contains. These characteristics of methanol and ethanol can cause problems with cold-start in light-duty spark-ignition engines. In fact, neat (100% pure) methanol will not start in typical spark-ignition engines at temperatures below about 45°F. This drawback is easily solved by the addition of 15-volume-percent gasoline, resulting in a blend referred to as M85. This amount of gasoline not only solves the cold-start problem, but makes methanol flames visible enough to allay safety concerns. (It is common practice to add 15-volume-percent gasoline to ethanol [E85] for the same reasons.)

---

[16] Ford Motor Company supplied almost all of the flexible-fuel methanol vehicles used in the AFV-FDP. The methanol percentage was low for several reasons. As part of a cooperative test plan with Ford, several of the flexible-fuel vehicles used only gasoline and many were purposely switched back and forth between gasoline and methanol. Also, early in the program, several of the planned methanol refueling facilities were not in place when the vehicles were delivered.

Figure 3.8 New York State Thruway Authority Methanol Flexible-Fuel Ford Taurus and M85 Refueling Facility

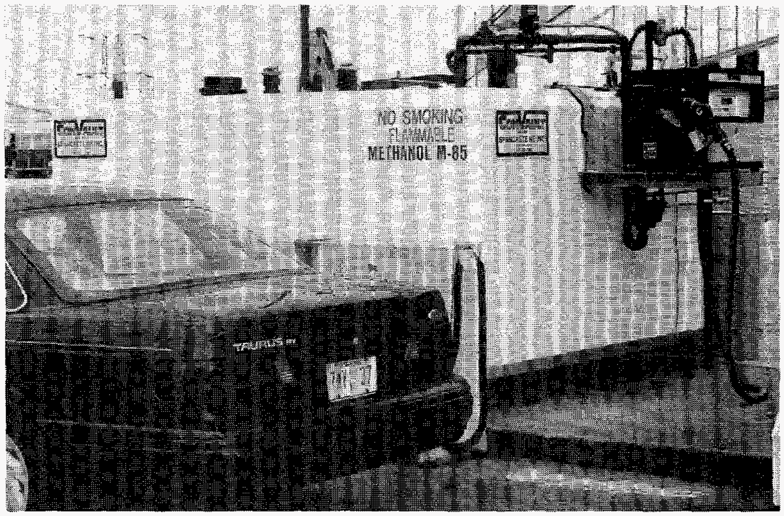


Table 3.6 Properties of Methanol and Ethanol, Compared to Gasoline

Fuel Property	Methanol[1]	Ethanol[2]	Gasoline[3]
Molecular Weight	32.04	46.07	100 to 105
Composition, Weight %			
Carbon	37.5	52.2	85-88
Hydrogen	12.6	13.0	12-15
Oxygen	49.9	34.8	0-4
Weight, lb/gal	6.6	6.6	6.0 to 6.5
Boiling Point, °F	149	172	80-437
Reid Vapor Pressure, psi @ 100°F	4.6	2.3	7-15
Latent Heat of Vaporization, Btu/lb	506	396	150
Lower Heating Value, Btu/gal	56,800	76,000	109,000-119,000
Solubility in Water, %	100	100	Negligible
Octane Number, (R+M/2)	99	100	87-93
Autoignition Temperature, °F	867	793	495
Flame Visibility	Invisible In Daylight	Difficult to See in Daylight	Visible Under All Conditions

[1] Assumes pure methanol
[2] Assures pure ethanol
[3] Nominal, varies with grade and composition of gasoline

Currently, methanol is made from natural gas by a process called steam reformation. Companies hoping to sell methanol at prices competitive with gasoline must start with a low-cost source of natural gas, such as a gas field too remote to justify building a pipeline to carry the gas to market, and where the owner of the gas is therefore willing to sell the resource cheaply. Companies are increasingly building plants for producing methanol and liquefied natural gas (LNG), and ocean tankers for transporting these liquid fuels, to develop natural gas resources outside the U.S. Thus, large-scale use of methanol might lessen the transportation sector's dependence on petroleum, but might not lessen U.S. dependence on foreign energy resources.

Methanol also can be made from coal—one such plant exists in the U.S. in Tennessee—but production from coal is environmentally unattractive because of the significant CO_2 emissions released during production. Methanol can be made from cellulosic wastes such as paper garbage, but the current technology for production is not economically competitive with steam reformation of natural gas.

Ethanol is currently made by fermenting sugars from corn, although other grains also can be used. Ethanol made via fermentation is expensive and debate continues about whether the energy used to produce crops and then convert them to ethanol is greater than the energy content of the ethanol fuel. On the plus side, much of the energy used to produce ethanol is derived from natural gas, propane, and coal, which are all largely domestic resources. Thus, even if the energy balance is questionable, the net result of ethanol use in vehicles would be a reduction in both imported energy and dependence on petroleum fuels.

Note that methanol and ethanol already play a small role in providing fuel to conventional vehicles. Ethanol is used in a 10% blend with gasoline commonly called gasohol. Gasohol is popular in the Midwest, and has been sold in New York State for use in gasoline vehicles. Ethanol used in gasohol represents about 0.7% of all gasoline sold in the U.S. Also, methyl tertiary butyl ether (MTBE), an oxygenate made from methanol and isobutylene, is used in oxygenated and reformulated gasoline and represents about 2.5% of all U.S. gasoline [7].

Fuel Specifications. During the AFV-FDP, the American Society for Testing and Materials (ASTM) developed specifications for M85 and E85 [8][9]. Both specifications define three classes of fuel that vary in gasoline content and vapor pressure (see Table 3.7). The classes are designed to ensure that M85 and E85 have sufficient vapor pressure to achieve acceptable cold starts in all areas of the country during all months of the year. Although these specifications were not finalized in time to guide initial M85 and E85 purchases for the AFV-FDP, their early drafts were the basis for the M85 fuel-purchase specifications developed and used. Unfortunately during the winter months, the M85 supplier was not able to deliver M85 to meet the desired Class 3 vapor-pressure specification. As a result, some difficulty with cold-starts

Table 3.7 ASTM Methanol and Ethanol Volatility Classes

Properties	Class 1	Class 2	Class 3
Fuel Methanol (M70-M85)			
Methanol + higher alcohols, min, volume%	84	80	70
Hydrocarbon/aliphatic ether, volume%	14-16	14-20	14-30
Vapor pressure, kPa (psi)	48-62 (7.0-9.0)	62-83 (9.0-12.0)	83-103 (12.0-15.0)
Fuel Ethanol (Ed75-Ed85)[1]			
Ethanol + higher alcohols, min, volume%	79	74	70
Hydrocarbon/aliphatic ether, volume%	17-21	17-26	17-30
Vapor pressure, kPa (psi)	38-59 (5.5-8.5)	48-65 (7.0-9.5)	66-83 (9.5-12.0)

[1] Ed stands for ethanol-denatured.

was reported, and the Thruway Authority resorted to adding gasoline to its M85 to increase its vapor pressure during the coldest part of the year. This remedy was adequate for the FFVs using M85.

Fuel Quality. Fuel quality is an important issue with alcohol fuels, with water contamination a potential problem. Gasoline will absorb only a very small amount of water; however, water is 100% miscible in methanol and ethanol, meaning that significant amounts of water could potentially enter a vehicle and degrade its performance.[17] In the AFV-FDP, only one instance of higher-than-typical water content occurred (0.26% compared to a specification maximum of 0.50%). Another fuel-quality issue is chloride contamination, the primary source of which is tankers that have previously contained chlorinated solvents. Two instances of high chloride content were observed during the AFV-FDP, but no engine damage occurred because fuel analyses caught the problem early enough. As the infrastructure to store and distribute alcohol fuels develops, problems with fuel quality are likely to diminish.

[17] Initial additions of clean water to alcohol are beneficial in that they increase the octane rating. (Each incremental addition has smaller effects.) However, water does not have any energy value and fuel economy will be decreased in proportion to the water content of the fuel. Because water that infiltrates the fuel during storage and transport usually carries impurities that cause corrosion or physically block filters, the water content of alcohol fuel is limited by specification.

Fuel Toxicity. Because methanol is poisonous,[18] prolonged exposure to vapors, contact with skin, and ingestion are to be strictly avoided. The addition of 15-volume-percent gasoline makes the fuel smell like gasoline, discouraging consumption. Ethanol is contained in alcoholic beverages and, to prevent fuel-ethanol from being consumed by humans, is denatured by adding five-volume-percent gasoline before it leaves the production plant. (Other ethanol denaturants are approved for use in providing a repulsive smell, but gasoline is the least expensive and most popular.)

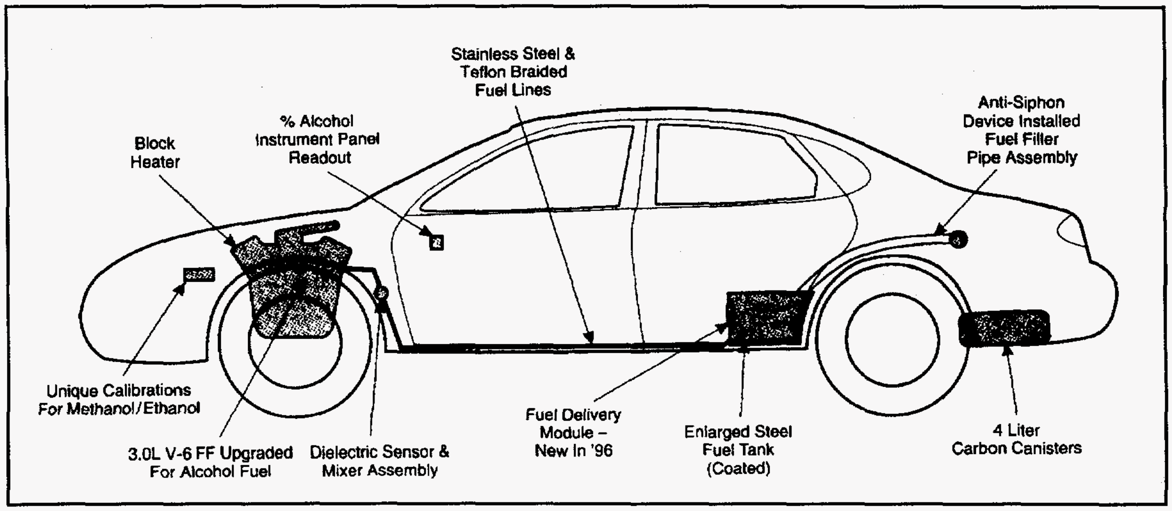
Energy Storage Density. Both methanol and ethanol contain less energy per gallon than gasoline. Even after the addition of 15-volume-percent gasoline, it takes 1.75 gallons of M85 and 1.40 gallons of E85 to equal one gallon of gasoline. The fuel tanks of OEM M85 and E85 vehicles hold only an extra two gallons or so of fuel compared to similar gasoline vehicles. A typical light-duty gasoline passenger car has a 16-gallon fuel tank and an operating range of about 350 miles. Operating on M85 and assuming the same fuel efficiency and a two-gallon increase in tank size, the range would be 225 miles. For E85, the range would be 280 miles. Thus M85 and E85 vehicles suffer a range-limitation problem similar to that of CNG vehicles, although less severe.

Alcohol Vehicle Fuel Systems. Because M85 and E85 are very similar to gasoline, analogous vehicle technology can be used. Figure 3.9 shows the modifications made by Ford Motor Company to its gasoline-powered 1996 Ford Taurus to accommodate M85 and E85. The changes include higher flow-capacity fuel injectors and fuel system material changes to be compatible with M85 and E85. (Alcohol fuels, especially methanol, are more aggressive towards fuel system materials than gasoline.) This is a flexible-fuel vehicle (FFV) that can run on any combination of methanol/ethanol and gasoline, and it incorporates a sensor to tell how much alcohol is in the fuel (Ford certifies its FFVs to be either M85 or E85 vehicles). Because gasoline can be used, this vehicle does not have the range limitation of dedicated alcohol vehicles. The engine computer adjusts the fuel-injection and ignition systems to accommodate the range of possible fuel mixtures from 100% M85 or E85 to 100% gasoline. An enlarged evaporative canister is included to contain the increase in vapor pressure that occurs when M85 or E85 is mixed with gasoline [10].

Incremental Vehicle Cost. Many of the FFVs in the AFV-FDP were prototypes built in small quantities and cost about $2,000/vehicle more than comparable gasoline-only models. Several analyses have estimated that FFVs built in large quantities would cost about $300/vehicle more to manufacture than

[18] Ingesting more than a few ounces of methanol can cause blindness or death. While gasoline is not poisonous, ingestion of gasoline can cause death due to chemical pneumonia. Gasoline also includes benzene, a known carcinogen, and other suspected carcinogens.

Figure 3.9 1996 Ford Taurus Changes to Use M85 or E85
(Source: Reference 10)



conventional counterparts, taking into account the fuel sensor, materials changes, and other modifications. Recently, manufacturers have offered FFVs at the same price as, and in some cases for several hundred dollars less than, the price of conventional vehicles, presumably as an incentive to get buyers to try this new technology.

Incremental Vehicle Cost. To date, the auto manufacturers have offered FFVs for sale at the same price as or a few hundred dollars lower than their gasoline-only models. However, several engineering-cost analyses have estimated that the extra cost to produce an FFV is about $300 per vehicle to account for the fuel sensor, materials changes, and software upgrades, and it is assumed that FFVs in the future will be priced to reflect this difference.

Vehicle Power, Acceleration, and Drivability. The AFV-FDP experience indicates that FFV drivability is as good using M85 or E85 as it is using gasoline. FFVs have been shown to accelerate more quickly with M85 than with gasoline. Similar increases should occur for FFVs using E85 because its fuel characteristics are similar to those of M85. This increase in power does not entail increased emissions or decreased efficiency compared to gasoline operation.

Fuel Efficiency. The AFV-FDP's extensive data show that FFVs using M85 are 7% more fuel-efficient than they are when using gasoline. On a gasoline-equivalent basis, this means that an FFV that achieves 20 mpg using gasoline will achieve the equivalent of 21.4 mpg using M85. However, expressed in M85 gallons, the fuel economy is 12.2 mpg. It is likely that a similar situation exists for FFVs using E85, although insufficient data exist to know for sure.

Fuel Costs. The price of methanol has moved up and down dramatically over the past few years. In the early 1990s, methanol was purchased for the AFV-FDP at $0.50 per methanol gallon (before taxes) for a full-tank truck delivery of 9,000 gallons. In 1995, an accident at a major methanol-producing facility in Texas and high demand for MTBE production caused the price of methanol to increase drastically, although the price has since returned to pre-1995 levels. The Gulf Coast spot price for methanol in the first nine months of 1996 varied between $0.35 and $0.50 per gallon, with the median price being about $0.40 per gallon.[19] When distribution costs, dealer markup, and taxes are included, this translates to a pump price of methanol in the range of $0.77 to $1.13 per methanol gallon, depending on volume. Compared with gasoline at $1.17 per gallon, the cost of methanol for the same amount of energy would be $1.35 to $1.98 (gasoline gallon equivalent). Some of the literature indicates that in the long term, methanol could be cost-competitive with gasoline, but major investments in production and distribution facilities would be necessary. Major oil companies and other potential sources of private capital have not shown interest in promoting methanol, other than to invest in facilities to produce it for use in providing oxygenates (e.g., MTBE) in oxygenated and reformulated gasolines.

Ethanol used in the AFV-FDP was donated by New Energy, Inc., and much less experience is available to help estimate the price of ethanol if it were sold at commercial service stations in New York State. However, knowing typical wholesale prices for ethanol, and estimating transport and overhead costs, it is possible to determine a reasonable estimate of ethanol's pump price. Such an estimate yields a price range of $1.22 to $1.46 per ethanol gallon. Compared to gasoline at $1.17 per gallon, the cost of ethanol for the same amount of energy would be $1.83 to $2.19 (gasoline-gallon equivalent). These numbers include the effect of preferential federal tax treatment that, if eliminated, would add more than $0.54/gal to ethanol's pump price. (See Appendix L for a discussion of alternative-fuel road taxes in New York State and at the federal level.) Ethanol is likely to remain an expensive fuel because its production process is inherently costly. Researchers are developing ways to make ethanol from cellulose-based crops and waste products that eventually could make ethanol cost-competitive with gasoline.

Other Operating and Maintenance Costs. As should be expected because their only additional part is the fuel sensor, the FFVs in the AFV-FDP have been as reliable and durable as their counterpart gasoline-only vehicles. While many fuel system parts were changed to incorporate different materials or coatings to

---

[19] Hart's 21st Century Fuels, September 1996, Vol. 16, No. 9.

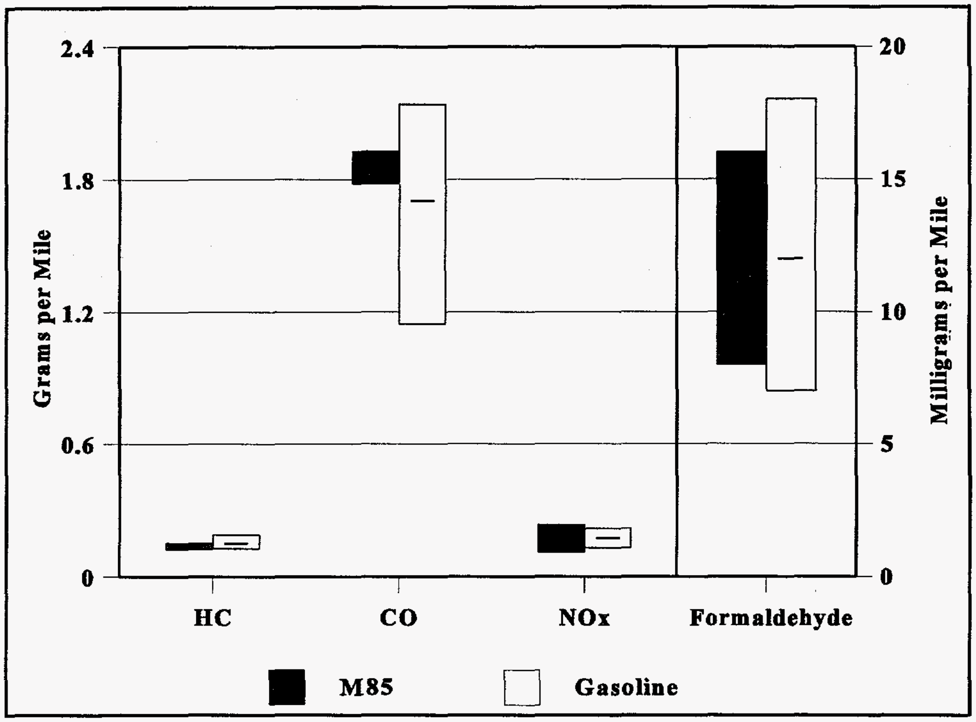
protect them from the greater corrosiveness of alcohol fuels, the basic function and configuration of the parts were not changed. The largest group of FFVs in the AFV-FDP consisted of 45 1993 Taurus sedans provided by Ford and operated by the New York State Thruway Authority. These vehicles were field-test prototypes of a larger group of FFVs that Ford was planning to produce. As of September 1995, these 45 cars accumulated more than 2.3 million miles using M85 and gasoline and experienced no problems with fuel sensors or other fuel system components, boding well for anticipated long-term durability. Analyses of these vehicles' lubricating oil have shown wear metals (trace amounts of metal that rub off engine parts during normal use) on average are higher when using M85 instead of gasoline, but the difference is deemed to have no significant impact on engine durability. Based on AFV-FDP experience, O&M costs (exclusive of fuel) of M85 and E85 vehicles should be similar to those of gasoline vehicles.

Methanol and ethanol are currently expensive, but FFVs are the least expensive AFVs.

Emissions. Emissions (exhaust, evaporative, running losses, and refueling) from FFVs using methanol or ethanol are typically very similar to those from gasoline, but methanol and ethanol emissions are less reactive in the atmosphere. Figure 3.10 illustrates the average tailpipe emissions for the Ford Taurus FFVs in the AFV-FDP. All the emissions are very similar whether operating on M85 or gasoline.

Early in the AFV-FDP, a group of four prototype FFVs based on the 1986 Ford Crown Victoria were subjected to extended use (i.e., driven an average of more than 100,000 miles each) on M85 and gasoline, and emissions tests showed that these vehicles demonstrated lower emissions-deterioration rates over the vehicles' lifetimes, compared to similar gasoline vehicles, presumably because M85 and E85 contain significantly less sulfur. This means that FFVs using alcohol fuels would have lower emissions over the vehicles' lifetimes. However, a drawback for most alcohol-fuel FFVs is higher aldehyde (formaldehyde and acetaldehyde) emissions than with straight gasoline, creating a direct health concern and promoting ozone production in the atmosphere. The Taurus FFVs in the AFV-FDP demonstrated a wide range of aldehyde emissions, with no significant difference, on average, between using M85 and gasoline (Figure 3.10). This result was not typical in that FFVs using methanol usually have significantly higher formaldehyde emissions compared to using gasoline, while FFVs using ethanol have higher acetaldehyde emissions.

Figure 3.10 1993 Taurus FFV Exhaust Emissions
(Note: Bars represent range of results; lines represent averages)



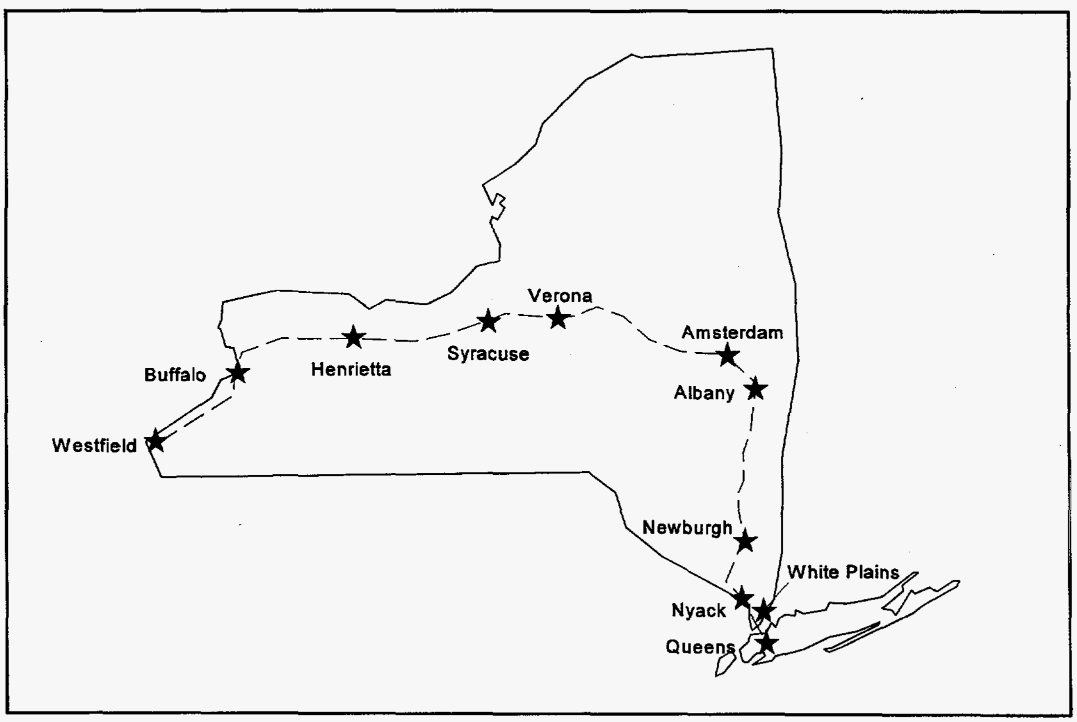
Greenhouse Gases. The CO_2 emissions of methanol vehicles are about 94% those of similar gasoline vehicles, assuming they have the same fuel efficiency. In the AFV-FDP, FFVs using methanol were found to use 7% less energy than when using gasoline. Combining increased fuel efficiency with the inherent combustion advantage of methanol yields CO_2 emissions that are only 87% those of gasoline vehicles. However, producing methanol releases almost half as much more greenhouse gases than producing gasoline does. When the entire fuel cycle from resource through combustion is included, methanol has very similar greenhouse gas emissions relative to gasoline [3][4]. (See Appendix F for an explanation of greenhouse gases and global warming.) The greenhouse gases from advanced methanol vehicles could be reduced by using more efficient engines or fuel cells.

Ethanol vehicles' CO_2 emissions are about 97% those of similar gasoline vehicles with the same fuel efficiency. However, for ethanol produced from corn (currently the feedstock used most), all the CO_2 produced from combustion in the vehicle is from carbon in the corn. This carbon came from atmospheric CO_2 absorbed by the corn plants for growth. Using ethanol in vehicles thus creates only a small increase in greenhouse gas emissions, from vehicle emissions other than CO_2. However, production of corn from which ethanol is made creates almost three times the greenhouse gas emissions that refining crude oil to gasoline does. Overall, the full fuel cycle greenhouse gas emissions for ethanol produced from corn are similar to those of gasoline from crude oil [3].

The U.S. Department of Energy is working on technologies to produce ethanol from cellulosic materials such as waste paper and fast-growing hybrid trees [11]. The cost of ethanol produced from these sources might be low enough to compete with petroleum fuels. Ethanol produced from cellulose is also believed to produce full fuel cycle greenhouse gases that are only about 60% those of gasoline from crude oil [3].

Refueling Infrastructure. In support of 45 Taurus and other methanol FFVs operated by the Thruway Authority, the AFV-FDP established M85 refueling facilities at nine locations along the length of the Thruway, from Westfield in Chautauqua County to Nyack in Rockland County (see Figure 3.11). The AFV-FDP also helped establish M85 refueling facilities in White Plains and Queens to support demonstration vehicles operated by the City of White Plains and New York City, respectively. The Queens station is the only one readily accessible to the public and is owned by Sun Oil Company. The AFV-FDP also helped establish an E85 refueling facility for use by the City of White Plains. Alcohol vehicle refueling equipment is very similar to that used for gasoline vehicles, the primary difference being the use of more corrosion-resistant materials and coatings.

Figure 3.11 M85 Refueling Facilities in New York State



Garage Safety Modifications. Facilities designed to store and maintain gasoline vehicles need very little modification for methanol or ethanol vehicles. If not already present, eye-wash facilities should be installed to allow a person to quickly flush their eyes with water in the event methanol or ethanol is sprayed into them. Absorbent material to clean up spills also needs to be available (the absorbent used becomes a hazardous waste). In those facilities with water and oil separators in their drainage systems, care must be taken to prevent methanol or ethanol from entering these separators for both safety and environmental reasons. Wastewater containing methanol or ethanol must be treated before being released.

Other Safety Issues. No methanol or ethanol safety incidents, including spills, ingestion, or fires, have occurred in the AFV-FDP. The reasons for this include safety training and the fact that all vehicle and refueling equipment is derived from gasoline service and thus is thoroughly proven.

Summary. Knowledge gained from the AFV-FDP indicates that methanol and ethanol are well-suited to light-duty vehicles with spark-ignition engines, giving them increased power and lower reactive emissions compared to gasoline, with little impact on vehicle cost (see Table 3.8). Vehicle range will be reduced (up to 50%) unless fuel storage capacity is increased. Overall greenhouse gas emissions, from resource through end-use, would be similar to those from gasoline. Ethanol made from cellulose could reduce greenhouse gas emissions by up to 40% relative to gasoline. Methanol (through MTBE) and ethanol are already key components in modern gasoline blends and increased use of alcohols in the existing fuel-

Table 3.8 Methanol FFV[1] Attributes Relative to Gasoline Vehicles

Range	Shorter
Acceleration	Slightly Better
Drivability	Same[2]
Fuel Economy (Energy Basis)	7% Better
Exhaust Emissions	Same
Refueling, Evaporative, and Running Loss Emissions	Same
Ozone-Forming Emissions	Lower
Greenhouse Gases	Same
Incremental Vehicle Price	$0 to $1,200[3]

[1] All comparisons made for M85 operation compared to gasoline operation
[2] Cold-start inferior unless fuel blended properly in winter
[3] The majority of FFVs have been sold for $0 incremental price to date, though Ford advertises the retail price of their Taurus FFV to be $1,165 more than the gasoline version.

distribution system is possible through targeted changes in parts to ensure that materials are compatible. The primary drawback to methanol and ethanol is that they currently cost significantly more than gasoline. Reducing this cost differential would require large investments in production facilities and, in the case of ethanol, breakthroughs in production technology. Garage safety modifications to store and maintain methanol or ethanol vehicles are relatively minor and inexpensive.

LPG/Propane

- *Five New York State Office of Parks, Recreation and Historic Preservation gasoline vehicles were converted to operate exclusively on propane as part of the AFV-FDP.*
- *These vehicles traveled an average of 654 miles per month and consumed the gasoline equivalent of 34 gallons per month of propane.*
- *Over the course of the AFV-FDP, these vehicles underwent 47 emissions tests.*

Physical Properties and Production. LPG[20] stands for liquefied petroleum gas. This fuel is often called propane, the primary constituent of LPG sold in New York State. Propane is sold as fuel for a broad assortment of equipment, ranging from fork-lift trucks to barbecue grills, and in rural areas it is widely used for residential and commercial heating and cooking. Propane has been used as a highway fuel for many years; many of the trucks that deliver bulk propane use it for engine fuel. The generally accepted specification for propane used in vehicle engines is known as HD-5, which is composed predominately of propane with limits on butane and propylene content (2.5 and 5.0 volume percent, maximum, respectively). Table 3.9 lists some general properties of pure propane compared to gasoline. Since this discussion centers on transportation fuels, use of the term propane elsewhere in this report generally refers to fuel conforming to the HD-5 specification.

About two-thirds of the propane in the U.S. is a by-product of natural gas production, with the remainder a by-product of crude oil refining. Propane is distributed throughout the U.S. primarily by pipelines and tank trucks. In New York State, a pipeline carries propane eastward across the State, with terminals at Watkins Glen, Oneonta, and Selkirk, where the propane is loaded onto tank trucks for distribution to users.

Besides home heating, cooking, and other miscellaneous uses, propane is used as a feedstock in the petrochemical industry. The U.S. Department of Energy predicts that if propane is used in large quantities

[20] LPG is a generic term used to describe mixtures of propane, propylene, butane, and butylene, or these hydrocarbons individually.

Table 3.9 Properties of Propane, Compared to Gasoline

Fuel Property	Propane[1]	Gasoline[2]
Molecular Weight	44	100 to 105
Composition, Weight %		
Carbon	82	85-88
Hydrogen	18	12-15
Oxygen	0	0-4
Weight, lb/gal	4.2	6.0 to 6.5
Boiling Point, °F	-44	80-437
Reid Vapor Pressure, psi @100°F	189	7-15
Latent Heat of Vaporization, Btu/lb	183	150
Lower Heating Value, Btu/gal	82,500	109,000-119,000
Octane Number, (R+M/2)	105	87-93
Autoignition Temperature, °F	855	495

[1] Assumes pure propane

[2] Nominal, varies with grade and composition of gasoline

as a vehicle fuel, its use in the petrochemical industry will cease [12] and that one-third of the increased demand for propane would be met by domestic sources while two-thirds would be met by imports (about 40% Canadian and 60% non-Canadian).

Energy Storage Density. Propane is unique among the alternative fuels in that it is gaseous, but becomes a liquid under modest pressure (i.e., under 300 psi). Although pressure vessels are needed to store propane, the relatively low pressures allow use of inexpensive steel tanks lighter than the tanks required to store CNG. In terms of energy content, it takes about 1.4 gallons of propane to equal one gallon of gasoline, but because propane's octane rating is significantly higher than that of gasoline (105 vs. 87-93), dedicated propane vehicles have the potential to use engines with compression ratios higher than those used for gasoline, yielding more power and better efficiency.

In addition to propane's lower per-gallon energy content, propane tanks are typically designed to prevent filling with liquid beyond 80% of the tank's full volume, to allow for expansion of the fuel, and the tanks are cylindrical to satisfy pressure vessel requirements efficiently. These factors tend to limit

> Propane is a liquid when kept under modest pressures.

the amount of propane that can be stored on a vehicle, resulting in a range reduction compared to similar gasoline vehicles.

Propane Vehicle Fuel Systems and Cost. Propane and CNG fuel systems are both called gaseous systems because the propane is vaporized before it enters the engine. Most propane vehicle fuel systems have a great deal in common with CNG fuel systems. Like CNG, many light-duty propane vehicles are bifuel vehicles with the propane fuel system added to an existing gasoline vehicle. According to the New York Propane Gas Association (NYPGA), propane fuel systems for light-duty vehicles (pickups, vans, and passenger cars) cost in the range of $2,000 to $2,200, including installation. As part of the AFV-FDP, NYPGA provided parts and labor to convert five light-duty trucks operated by the New York State Office of Parks, Recreation and Historic Preservation (OPRHP) to dedicated propane operation. The gasoline tank was removed from each vehicle, making room for a relatively large propane tank on the vehicle's underside. Some of the vehicles had two 13-gallon propane tanks installed, giving them similar operating ranges to gasoline vehicles. Nonetheless, OPRHP propane-vehicle drivers were concerned about the operating range of their dedicated propane vehicles because of the few propane refueling stations convenient to them.

Vehicle Power, Acceleration, and Drivability. Like CNG, propane enters the engine fully vaporized, reducing the amount of air that can enter the engine, and adversely affecting engine power compared to operation using gasoline. The power loss often increases acceleration times by 10 to 20%, although in the AFV-FDP drivers were observed to quickly acclimate and in general not find the loss in power to be detrimental to operation of the vehicle. Propane fuel systems are heavier than gasoline fuel systems, but typically by less than 100 pounds, so vehicle performance decrease due to fuel-system weight increase usually is not a significant problem. In the AFV-FDP, drivability was generally reported to be adequate, although propane vehicles can suffer cold-start problems similar to those experienced with CNG vehicles.

Fuel Efficiency. Vehicles converted from gasoline to propane have essentially the same fuel efficiency in energy per mile as when running on gasoline. Because 1.4 gallons of propane contain energy equivalent to that in a gallon of gasoline, a vehicle that gets 20 mpg using gasoline will generally get 14 mpg using propane.

Fuel Costs. The price of propane delivered on site is highly dependent on volume. In New York State, small volumes (1,000 gallons per year) may cost as much as $0.95 per propane gallon before taxes ($1.32 per gasoline-gallon equivalent). In larger volumes, the price could drop to below $0.60 per propane gallon. Federal tax on propane is $0.183 per gallon; the New York State tax and local taxes total $0.155 per gallon, for a total of $0.338 per gallon. (See Appendix L for a more complete discussion of alternative-fuel taxes in New York State.) Adding taxes makes the price of propane \$0.95 to \$1.29 per gallon (\$1.32 to \$1.81 per gasoline-gallon equivalent). If propane were dispensed in high volume at commercial stations, additional costs would be incurred to pay for the station operating costs. However, the wholesale price of propane would probably decline under such a scenario, with the net result being a propane price around \$1 per gallon (\$1.40 per gasoline-gallon equivalent) which could be competitive with gasoline.

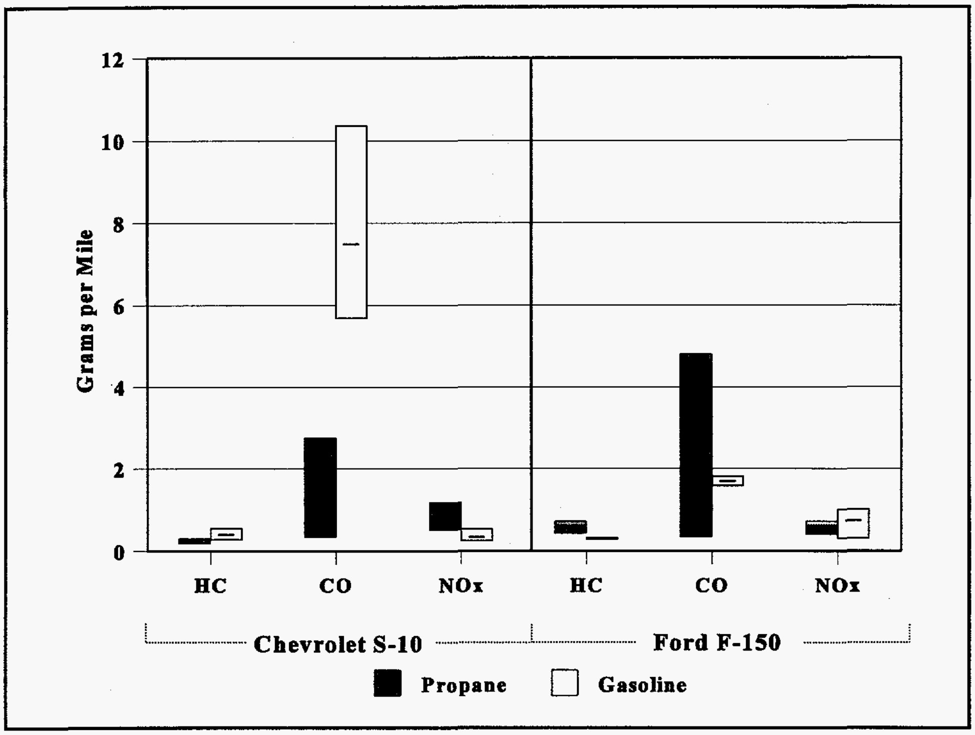
Propane varies in price seasonally due to its demand as a heating fuel in rural areas. A large transportation demand for propane would be more constant year-round and could help to dampen seasonal price changes, but the increased demand also might cause average propane prices to rise.

Other Operating and Maintenance Costs. Reliability and durability are similar for propane and gasoline vehicles. However, residue that can build up in the fuel converter of conventional propane-fuel systems must be removed periodically. This residue is believed to be primarily composed of heavy hydrocarbons picked up during production or from transport through pipelines that previously carried distillate or diesel fuel. The propane industry is working on fuel filters for both vehicles and propane dispensers to remove residue and minimize the additional maintenance it requires. Based on AFV-FDP experience, O&M costs (exclusive of fuel) of propane vehicles should be similar to those of gasoline vehicles.

Emissions. Like CNG vehicles, propane vehicle emission characteristics depend on how well the propane fuel system is integrated with the existing vehicle emission-control system (assuming the vehicle starts out as a gasoline vehicle). Compared to gasoline vehicles, well-integrated propane vehicles have similar HC, carbon monoxide, and oxides of nitrogen emissions; lower CO_2 emissions; and significantly lower toxic emissions. Figure 3.12 illustrates the emissions results of the Ford F-150 and Chevrolet S-10 pickup trucks used in the OPRHP demonstration. The Chevrolet S-10 showed reduced average CO emissions when using propane at the expense of increased NO_x emissions. The Ford F-150 showed increased average HC emissions when using propane. No other significant emissions difference was observed between using propane and using gasoline.

Even though propane did not achieve significant reductions in primary tailpipe emissions, it still has the potential to provide air-quality benefits compared to gasoline. The ozone-forming potential of the HC emissions from propane vehicles is only about half that of HC emissions from gasoline vehicles. Also, dedicated propane vehicles do not have evaporative and running-loss emissions. As with dedicated CNG vehicles, this suggests that dedicated propane vehicles have an overall ozone-forming potential about one-quarter or less that of gasoline vehicles. Propane vehicles' refueling emissions have the potential to be much lower than gasoline vehicles, although the lack of a refueling connection standard now results in a

Figure 3.12 Light-Duty Propane Vehicle Exhaust Emissions (Note: Bars represent range of results; lines represent averages)



wide variation in refueling emissions (there are several manufacturers of propane refueling nozzles, but no standard specifications, so the amount of "dead-space" where fuel is trapped and released varies). Even so, because the reactivity of propane is only about 15% that of gasoline, propane refueling emissions do not form ozone nearly as readily as gasoline refueling emissions do.

Greenhouse Gases. Because of the lower amount of carbon and higher amount of hydrogen in propane compared with gasoline, propane vehicles produce about 12% lower CO_2 emissions than similar gasoline vehicles (assuming the same fuel efficiency). When fuel production and other greenhouse gases are included, propane vehicles are estimated to have 10 to 20% lower overall estimated greenhouse gas impact than similar gasoline vehicles [3][4].

Refueling Infrastructure. Typically propane is dispensed from large aboveground storage tanks and the cost of a refueling station is relatively low, about equal to the cost of a gasoline refueling system. Although regulations in New York City preclude using propane as a vehicle fuel, elsewhere in New York State propane vehicles presently can refuel at about 150 sites. The propane industry is attuned to providing propane for vehicles used in fleets. Propane suppliers are well-equipped to place skid-mounted propane storage tanks and dispensers on site with fleet operators. Figure 3.13 shows one of the OPRHP propane

Figure 3.13 Refueling an OPRHP Propane Vehicle

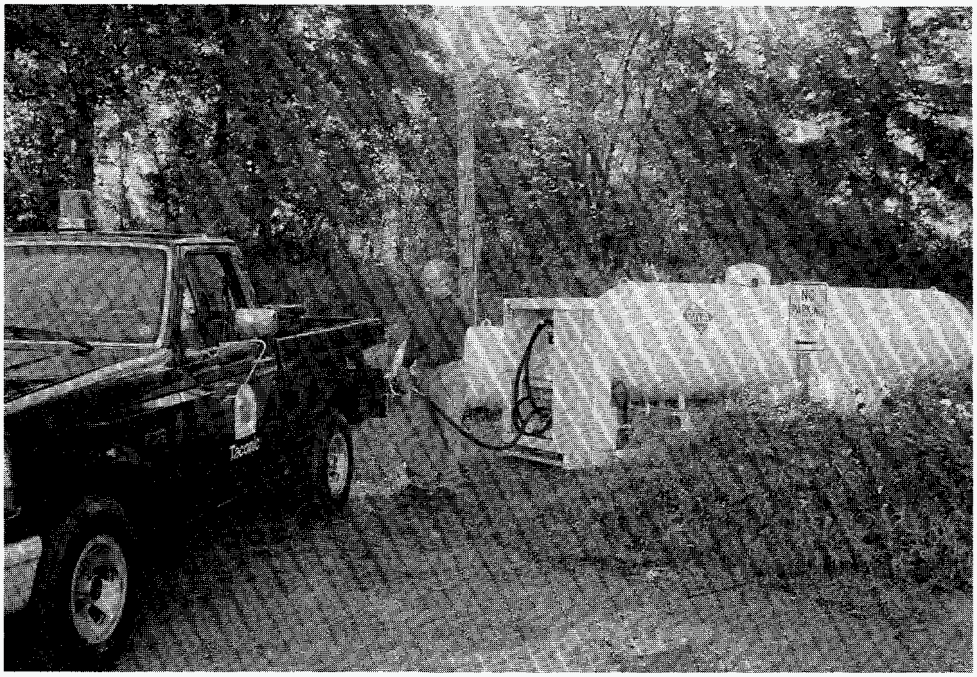
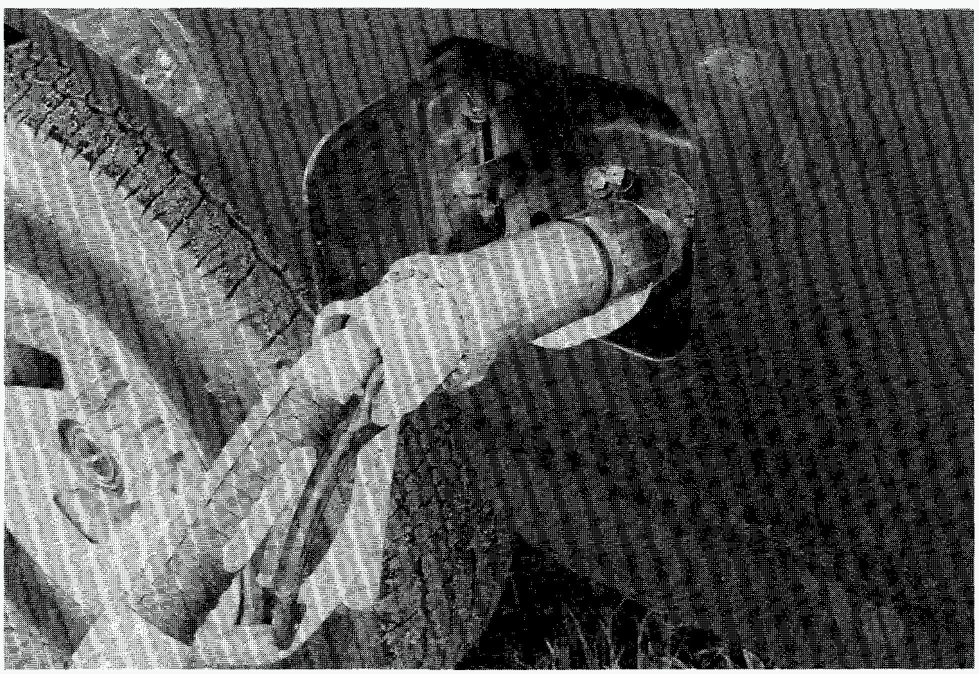


Figure 3.14 Propane-Refueling Nozzle



vehicles being refueled at an OPRHP facility, using a tank and dispenser provided by Agway Energy Products, the local propane supplier. Initially, the OPRHP propane vehicle users found the propane refueling system more difficult to operate than gasoline refueling equipment, slower to fill the vehicle, and to be perceived as less safe. Convenience and safety concerns were addressed by revised procedures, additional training, and substitution of a refueling nozzle configured more like a typical gasoline nozzle and easier to use (see Figure 3.14).

Garage Safety Modifications. Since the properties of propane differ from those of conventional fuels, servicing and storing propane vehicles in a facility designed for conventional fuel vehicles may require facility modifications. National code organizations, including the National Fire Protection Association (NFPA) and the Building Officials and Code Administrators (BOCA), have issued general guidelines for facilities servicing propane vehicles. These guidelines were used in the AFV-FDP, together with existing conventional fuel building codes, to identify possible electrical and mechanical modifications for garage facilities.

Both propane and gasoline vapors are heavier than air, filling depressions and low lying areas. Recommended garage design standards increase safety for both fuels by minimizing areas near the floor where vapors can accumulate, and by removing sources of ignition from low lying areas.

A safety evaluation of the OPRHP vehicle maintenance facility was conducted as part of the AFV-FDP to assess its suitability for storing and maintaining propane vehicles. Recommenda-tions were made for training, modify to the ventilation system, elimination of ignition sources, and installation of a combustible gas detection system.

Examination of the recommendations and evaluation of the safety risks, relative to the small number of propane vehicles in the fleet and the cost of ventilation and gas detection systems, resulted in the decision to modify vehicle storage and maintenance procedures rather than modify the site. Training on propane fuel properties, refueling procedures, and storage and maintenance safety procedures was conducted for the AFV-FDP by the New York Propane Gas Association.

Other Safety Issues. During the OPRHP demonstration, there were no safety-related incidents in operating or repairing the propane vehicles. There were safety concerns initially with the refueling system because of the possibility that propane could be released when the nozzle was not connected to the vehicle. These concerns were allayed by installing a refueling nozzle more convenient to use and by simplifying the sequence for turning on the propane system to allow refueling.

Table 3.10 Light-Duty Dedicated Propane Vehicle Attributes Relative to Gasoline Vehicles

Range	Varies[1]
Acceleration	Slower to Same
Drivability	Same
Fuel Economy (Energy Basis)	Same
Exhaust Emissions	Same[2]
Refueling, Evaporative and Running Loss Emissions	Lower
Ozone-Forming Emissions	Much Lower
Greenhouse Gases	Lower
Incremental Vehicle Price	$2,000 to $2,500

[1] Longer with bifuel, often shorter with dedicated
[2] Dependent on vehicle tune

__Summary__. The results from the AFV-FDP suggest that propane is a good light-duty vehicle fuel, with lower ozone-forming potential than gasoline and similar fuel efficiency (see Table 3.10). The overall greenhouse gas impact of propane vehicles is estimated to be about 10 to 20% lower than that of similar gasoline vehicles. The energy-storage density is less than that of gasoline, but better than CNG. Propane fuel systems cost about half as much as CNG fuel systems, although propane fuel prices are typically higher than prices of CNG and gasoline. Garage safety modifications to accommodate propane vehicles can be minor, and with appropriate training, equipment, and adherence to safety procedures, the overall risk of safety problems with propane is estimated to be similar to that with gasoline.

HEAVY-DUTY AFVs

Natural Gas

- *The AFV-FDP collected data from 31 dedicated CNG transit buses that used an early version of the Cummins L10G engine (see Figure 3.15).*
- *These transit buses averaged 2,557 miles per month and consumed the diesel-fuel equivalent of 771 gallons per month of natural gas.*
- *150 emissions tests were conducted on the Long Island Bus CNG buses (Figure 3.16) and 20 tests were conducted on diesel control buses.*
- *Two Kenmore-Tonawanda School District CNG school buses traveled 19,340 miles from May 1994 through September 1995 and consumed the diesel-fuel equivalent of 4,250 gallons of natural gas.*

Figure 3.15 The Cummins L10G Engine used in Natural Gas Transit Buses

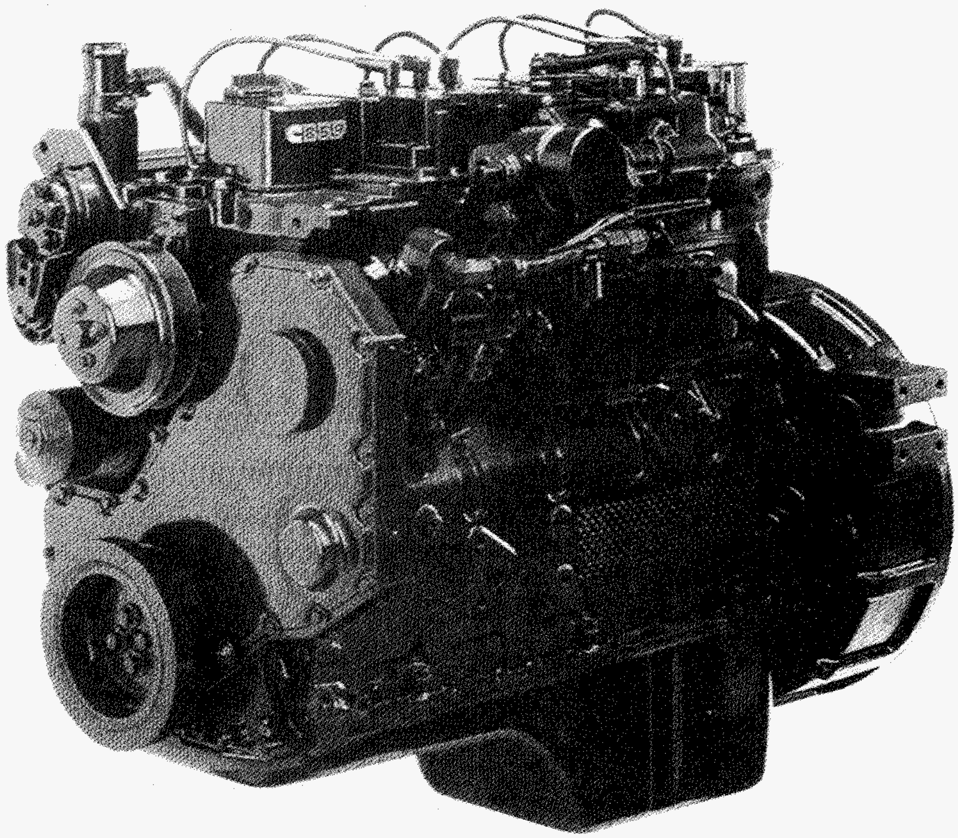
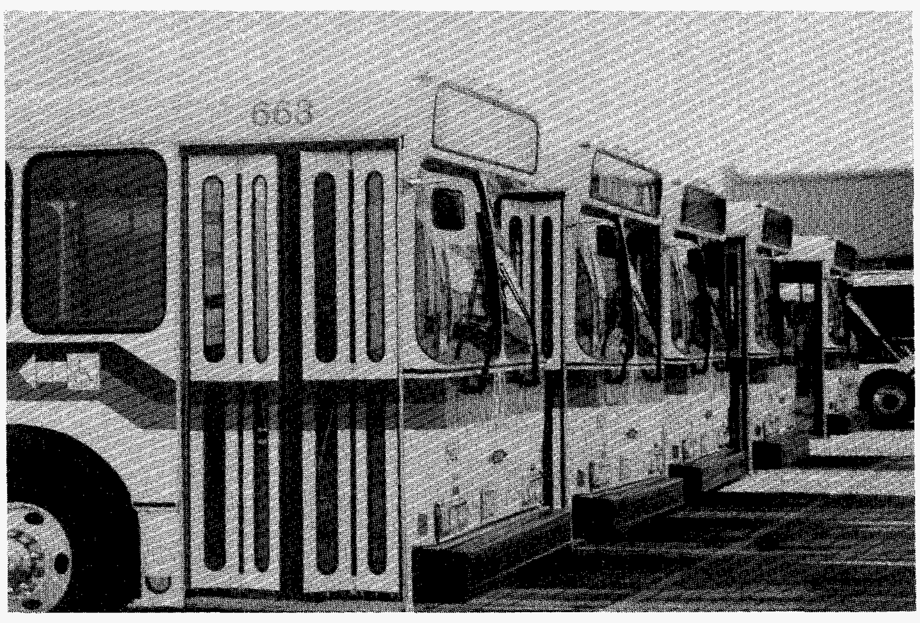


Figure 3.16 Long Island Bus CNG Transit Buses



Technology Status. The technology for using natural gas in heavy-duty trucks and buses is maturing very rapidly. While the CNG fuel-storage systems are similar to those for light-duty vehicles, the engines are spark-ignition adaptations of existing diesel engines (i.e., spark plugs are added and other modifications are made to enable diesel engines to use CNG). Initially, the only CNG engine fuel systems available were open-loop and mechanically controlled. While such systems were capable of very low emissions, they exhibited significant variability. In the AFV-FDP emissions tests, it was not unusual for the bus with the highest emissions to be 100% higher than the bus with the lowest emissions, even after all the buses had been tuned up prior to testing. In response, Cummins Engine Company, a leading manufacturer of both diesel and natural gas engines, has developed a natural gas engine fuel system incorporating a lean-burn feedback control that has demonstrated much less variability and has the same low-emissions capability demonstrated with previous fuel systems [13]. Other engine manufacturers appear to be developing similar systems.

A typical full-size CNG transit bus presently costs $40,000 to $50,000 more than a comparable diesel bus. As the production volumes of heavy-duty natural gas engines and CNG fuel systems increase, this incremental cost is likely to decrease significantly.

Vehicle Power, Acceleration, and Drivability. Heavy-duty natural gas engines are capable of the same or higher power output as diesel engines, in contrast to the typical power decrease when light-duty gasoline engines are converted to CNG. In the AFV-FDP, acceleration of heavy-duty CNG vehicles was slower than their diesel counterparts, although the drivers reported that overall drivability was as good as the diesels. Natural gas heavy-duty engines have potential for better starting in cold weather because of the elimination of typical problems in getting diesel fuel to flow and ignite in a cold engine, but experience in the AFV-FDP was insufficient to prove this benefit.

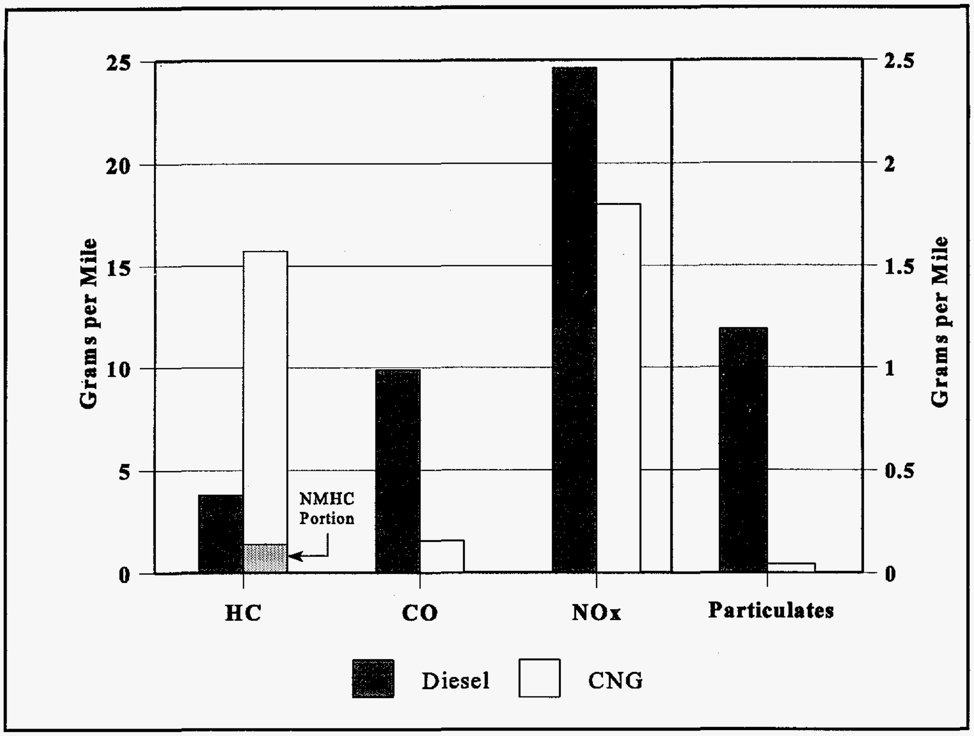
Fuel Efficiency. Natural gas spark-ignition engines have two inherent fuel-efficiency disadvantages compared to diesel engines: (1) the compression ratio must be reduced, increasing fuel consumption under all engine load conditions; and (2) a throttle (valve) must be added to the air intake, increasing fuel consumption at idle and other low-load conditions. At high engine loads and speeds, the efficiency difference between the two types of engines is small. Data from CNG and diesel transit buses participating in the AFV-FDP showed the CNG transit buses to consume 14 to 30% more energy than their diesel counterparts. Routes with many stops and large amounts of engine idling time tended to produce larger efficiency differences between CNG and diesel, while express routes with few stops and high average speeds tended to produce smaller differences. Engine designers have identified technical strategies that eventually could greatly reduce the efficiency difference between diesel and natural gas engines.

Fuel Costs. Fleets buying large quantities of fuel can normally obtain natural gas at a price that provides significant savings when compared to an energy-equivalent amount of diesel fuel, but additional factors must be taken into account when comparing per-mile fuel costs of heavy-duty CNG vehicles to diesel counterparts. Significant factors include the capital and operating costs of the refueling station, which are significantly higher for CNG, the generally lower efficiency of current CNG engines, and the impact of CNG's lower fuel taxes. Transit fleets in the AFV-FDP operated small groups of demonstration vehicles and were not able to take full advantage of economies-of-scale that could have reduced fuel acquisition and station costs. Also, they operated an older type of CNG engine and, since transit authorities are exempt from fuel taxes, they did not benefit from any tax savings. Despite these factors, these fleets achieved CNG per-mile fuel costs that were roughly equivalent to diesel costs. Future purchasers of heavy-duty CNG vehicles may benefit from improved economies-of-scale and higher-efficiency CNG engines. Fleets that are not tax-exempt can also benefit from a CNG tax savings that in New York State currently amounts to about 12 cents per gallon on an energy-equivalent basis, including the combined impact of federal, State, and local taxes (see Appendix L).

Other Operating and Maintenance Costs. Early heavy-duty natural gas engines suffered from a variety of problems associated with components, such as spark plugs and ignition wires, not found on diesel engines. Engineers have increasingly optimized these components for transit-bus and other harsh environments, such that the latest heavy-duty natural gas engines appear to be approaching the durability and reliability of diesel engines, and O&M costs for both types of engines should be similar. CNG transit buses monitored in the AFV-FDP actually had lower O&M costs when compared to diesel buses in the same fleets, but this was largely attributed to the lower age of the CNG buses.

Emissions. Figure 3.17 illustrates the dramatic emissions reductions that can be achieved by switching transit buses from diesel fuel to natural gas. Shown are AFV-FDP emissions test data indicating that the reactive portion of average natural gas HC emissions (i.e., NMHC) were about one-third those of diesel fuel HC emissions, which are all NMHC except for trace amounts of methane. (The vast majority of natural gas HC emissions are methane, which has very low reactivity.) The ozone-forming potential of the CNG buses is estimated to be less than half that of the diesel buses they are replacing. Average CO emissions from the CNG buses were only 16% as high as those produced by diesels. Average NO_x emissions were only 73% as high, and even lower emissions have been demonstrated by these engines following precise engine-management-system adjustments, and by other heavy-duty natural gas engines. Particulate emissions from the CNG buses were on average only five percent as high as those produced by diesels. Particulate emissions from CNG engines most likely come from engine lubricating oil consumption (i.e., oil that leaks into the combustion chamber) and not the fuel.

Figure 3.17 Average Transit Bus Emissions Using the New York City Bus Cycle (Long Island Bus CNG and Diesel Buses)



A recent cooperative effort between EPA and the heavy-duty engine manufacturers hopes to develop much cleaner heavy-duty diesel engines, but relies on the availability of clean diesel fuel. Also, such engines may be less fuel-efficient than current diesel engines, resulting in natural gas versions being more competitive in that regard.

__Greenhouse Gases.__ If heavy-duty natural gas vehicles have similar fuel efficiency to diesel heavy-duty vehicles, they should have 10 to 15% less overall greenhouse gas impact (resource through end-use) than diesel heavy-duty vehicles. However, in the AFV-FDP, the natural gas transit buses tested had fuel consumption between 14 and 30% higher than similar diesel buses. When the increase in fuel consumption is taken into account, the overall greenhouse gas impact is estimated to be between a three percent reduction and a 17% increase. Newer heavy-duty natural gas engines may consume less fuel, and the overall greenhouse gas impact should decrease proportionately.

__Refueling Infrastructure.__ Operators of CNG transit buses usually establish refueling facilities at the garages that provide standard overnight servicing (cleaning, etc.) and maintenance of buses. Large, optimally-sized stations can be built for \$13,500 to \$15,500 per bus, which is eight to nine times the cost of a typical new diesel fuel refueling facility for transit buses. Other than stations built by or for transit operators, little has been done to address the refueling needs of heavy-duty natural gas vehicles. The available public CNG stations generally are not equipped to fast-fill heavy-duty natural gas vehicles. Over-the-road heavy-duty natural gas truck owners have come to the consensus that the only way they can store enough natural gas on board is by liquefying it. Liquefied natural gas (LNG) must be maintained at -260°F to keep it liquid, which presents additional challenges for vehicle use. LNG allows heavy-duty vehicles to achieve operating ranges required on intercity routes, and refueling times are similar to diesel vehicles. However, no LNG public refueling facilities exist in New York State and LNG refueling-facility technology is still in an early phase of development. LNG refueling facilities are projected to cost less than similar size CNG refueling facilities. Assuming that LNG is distributed from a central point and delivered by tank truck to transit bus refueling stations, the stations are estimated to cost about $5,000 per bus. Alternatively, LNG can be vaporized to produce CNG, using equipment whose capital cost is much lower than that of a typical CNG station. An LNG-to-CNG refueling station is estimated to cost about $9,000 per transit bus.

Garage Safety Modifications. As with light-duty natural gas vehicles, a professional engineer should examine garage electrical and HVAC systems prior to introduction of heavy-duty natural gas vehicles, and safety training should be provided to transit personnel. In the AFV-FDP, natural gas leaked from buses at transit garages on several occasions but no injuries, fires, or property damage occurred, an outcome attributed in part to prior attention to training and facility design.

Transit bus garages have been optimized for handling diesel buses and often require modifications to safely and efficiently provide services to CNG buses. These modifications usually can be performed most cost-effectively if included as part of a new facility design or periodic facility refurbishment program, in which case the incremental cost of the CNG features can be very small. If the CNG modifications are done as an independent project, costs can be very high, potentially exceeding the cost of refueling equipment.

Summary. Heavy-duty natural gas engines have demonstrated power, acceleration, and drivability very similar to diesel engines. Compared to diesel fuel, natural gas has significant potential for reductions in particulate and ozone-forming emissions. The overall greenhouse gas emission impact (resource through end-use) is estimated to be between a three percent reduction and a 17% increase compared to diesel fuel. Heavy-duty CNG vehicles currently cost significantly more than diesel vehicles; they also tend to have significantly reduced fuel efficiency (14 to 30% increase in energy consumption) because at low loads spark-ignition CNG engines are less efficient than diesel engines. However, fuel costs are about the same, because natural gas is typically less expensive than diesel fuel and other O&M costs are estimated to be about equal. Transit bus operators and other purchasers of heavy-duty CNG vehicles normally must plan for installation of onsite refueling equipment and facility safety modifications, both of which may require significant investments, but these costs can be greatly reduced by careful planning. Buildings used to park or maintain heavy-duty CNG vehicles should be evaluated by a professional engineer to determine whether changes to the electrical or HVAC systems are recommended to establish a safe working environment, and all personnel should receive CNG safety training.

Methanol and Ethanol

- *The AFV-FDP converted three transit buses to use ignition-improved methanol in Albany and at JFK International Airport.*
- *These transit buses operated well, but fuel costs were prohibitively high.*
- *Modest emissions reductions were observed with these engines, although ozone-forming potential was reduced and particulate emissions were greatly reduced.*

Engine Technology. The technologies for using methanol and ethanol in heavy-duty vehicles are the same: specially built diesel engines or addition of ignition-improving additives to allow using these fuels in more-or-less conventional diesel engines. Regardless of the approach taken, the vehicle's fuel tanks and other fuel system components can be simple variations of diesel-fuel components. Detroit Diesel Corporation (DDC) developed the only alcohol heavy-duty engine (methanol and ethanol versions) ever sold on a commercial basis, the Model 6V-92TA. The methanol version of this engine was first put into service in New York City [14], where there are now 18 methanol buses operating. The 6V-92TA uses combustion-chamber electric-heating elements, called glow-plugs, and careful control of combustion chamber scavenging[21] to ignite of methanol or ethanol. This engine has been used in more than 300 methanol transit buses in Los Angeles[22] and several ethanol transit buses and trucks in the Midwest.

Ignition-Improving Additives. Instead of using a special engine, ignition-improving additives, accompanied by minor fuel-injection system modifications, are a means by which methanol or ethanol can be used in any diesel engine. These additives raise the cetane number[23] of methanol or ethanol so they have similar ignition characteristics to diesel fuel. A common ignition-improver is Avocet®, but based on

---

[21] The 6V-92TA is a two-stroke engine. By controlling the amount of scavenge air, combustion radicals are retained in the combustion chamber to assist with initiating combustion of the subsequent charge of fuel and air.

[22] The Los Angeles MTA is also experimenting with ethanol as a fuel and has converted some of its methanol buses to ethanol.

[23] Cetane number of fuels for diesel engines is analogous to octane number of fuels for spark-ignition engines.

experience in the AFV-FDP, the cost of Avocet®, combined with the already high cost of methanol and ethanol, make the use of ignition-improved alcohol highly uneconomic at this time.

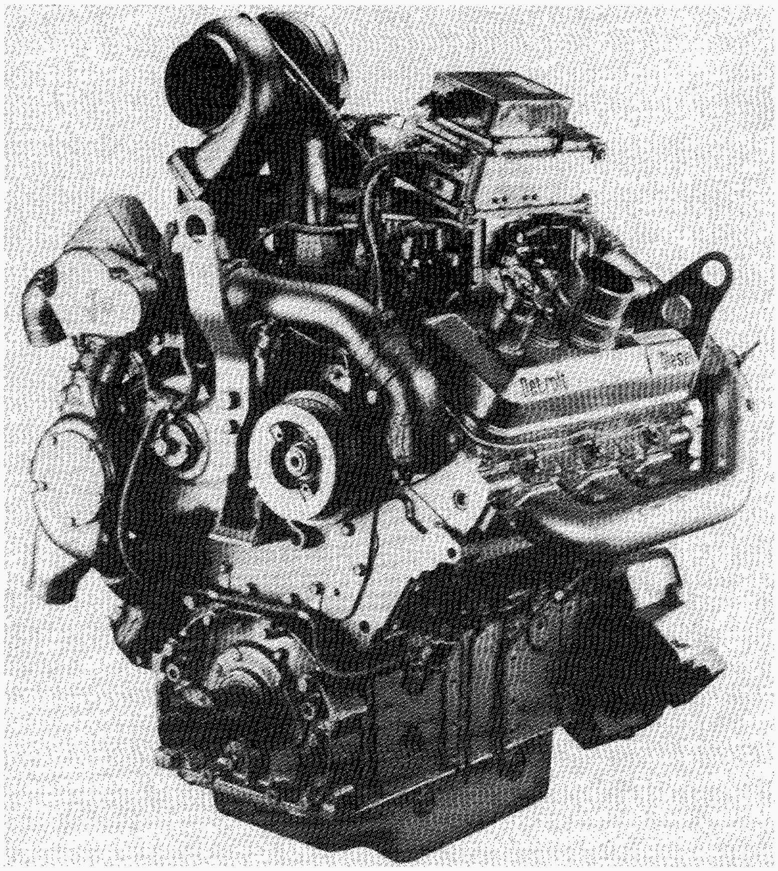
Vehicle Power, Acceleration, and Drivability. Heavy-duty vehicles using alcohol engines have no difficulty achieving the same performance as their diesel-fuel counterparts, partly because alcohol combustion does not create soot. Combustion of diesel fuel under heavy engine-load conditions causes soot formation, which must be limited for environmental reasons, and is a major limiting factor on diesel-engine power. Because alcohol engines are free of this constraint, they can easily match the power output of their diesel-fuel counterparts. In fact, diesel buses converted to ignition-improved methanol in the AFV-FDP exhibited improved power output with methanol. Also, cold-starting is improved with alcohol fuels because of better flow properties at cold temperatures compared to diesel fuel.

Fuel Efficiency. The DDC 6V-92TA alcohol engine is less efficient than its diesel counterpart at low loads and speeds. At high loads and speeds, the efficiency difference is small. Overall, the fuel consumption of the methanol transit buses operating in New York City was 13% higher on an energy-equivalent basis, as compared to diesel buses. Other fleets using this engine have reported 5 to 25% more energy used with methanol, as compared with diesel-fuel engines.

Fuel Costs. The economic impact of the high energy consumption of heavy-duty methanol engines is compounded by the higher price of methanol compared to diesel fuel on an energy basis. Together these factors greatly discourage the use of methanol in heavy-duty vehicles that use large amounts of fuel. At current methanol prices (about $0.40 per methanol gallon), and considering methanol's lower efficiency and the fact that a gallon of methanol contains less than half the energy of a gallon of diesel fuel, fuel operating costs for heavy-duty methanol vehicles are two to three times higher than when using diesel fuel. The fuel costs when using ethanol would be about the same as for methanol. The price of alcohol fuels is expected to remain high and, if ignition-improving additives are used, the fuel price could increase by four to five times over using straight alcohol.

Other Operating and Maintenance Costs. The heavy-duty methanol vehicle projects conducted as part of the AFV-FDP included only a few experimental vehicles and these limited evaluations were not conducive to collecting representative O&M costs other than fuel costs. The AFV-FDP projects also were not conducted for long enough periods of time to draw firm conclusions about O&M costs. Only a few organizations outside of the AFV-FDP have used heavy-duty methanol vehicles over long periods of time and indications are that O&M costs were increased, but conclusive findings probably are not warranted because even these vehicles were built at an early point in the evolution of heavy-duty methanol technology.

Figure 3.18 DDC Heavy-Duty Methanol Engine



Emissions. The alcohol version of the DDC 6V-92TA was by far the cleanest heavy-duty engine when it was certified for emissions in 1991. (The engine was first used in revenue service in 1983.) Alcohols produce no particulate emissions when combusted and very low levels of oxides of nitrogen; however, alcohol heavy-duty engines do produce higher aldehyde emissions when using alcohols, as compared to diesel fuel.

Greenhouse Gases. For an equal amount of fuel energy, methanol combustion produces 6% less CO_2 emissions than diesel fuel, though this advantage is erased by the additional greenhouse gases produced during methanol production relative to diesel fuel production. Also, methanol heavy-duty engines in transit buses have demonstrated fuel energy consumption between 13 and 25% higher than similar diesel engines. Accounting for the CO_2 emissions from the relative increase in fuel energy consumed, the greenhouse gases of heavy-duty methanol transit buses would be expected to increase a similar percentage as the increase in fuel energy used relative to diesel fuel.

Refueling Infrastructure and Garage Modifications. In the AFV-FDP and elsewhere, heavy-duty alcohol vehicles have used onsite refueling facilities in fleet settings rather than relying on public refueling facilities. The refueling equipment and handling practices for alcohols are very similar to those for diesel fuel, and should not present cost or personnel training hurdles. Modification of garages designed for diesel buses should be limited to availability of eye-washes, if not already present, and a ready supply of absorbent to clean up spills. Care must be taken to prevent spilled methanol from being washed down the drain since the water and oil separators that would catch spilled diesel fuel will not separate out methanol.

Summary. Methanol and ethanol perform well in heavy-duty vehicles. The vehicle modifications are not costly, much existing infrastructure can be used, and they have attractive emissions characteristics. However, their high cost per gallon has discouraged potential users. DDC has discontinued offering its 6V-92TA alcohol engine for sale both because of lack of demand and because the diesel engine upon which it is based has been superseded by an improved engine, the Series 50. Heavy-duty engine manufacturers appear to have shifted their focus to developing heavy-duty natural gas engines.

The high price of methanol and ethanol is a substantial hurdle to their use in heavy-duty vehicles.

LPG/Propane

Heavy-duty engines designed for propane are just currently becoming available and none were tested as part of the AFV-FDP. (Ford offers medium-duty trucks configured for propane, but these trucks use medium-duty spark-ignition engines that are not suitable for heavy-duty vehicle applications such as transit buses or large tractor trailers.) Western Star Trucks Ltd. is in the process of building the first heavy-duty trucks powered by propane. The trucks will use the Caterpillar 10-liter G3306 engine configured for propane and based on the well-established 3306 diesel engine. The propane G3306 emits less than 1.0 gram of oxides of nitrogen and 0.02 grams of particulate per brake horsepower hour, using a three-way catalyst for emissions control [15]. These emission results are below ULEV heavy-duty engine standards and are the lowest heavy-duty engine emissions reported to date. DDC and Cummins also are believed to be developing heavy-duty propane engines. Emissions from heavy-duty propane engines should be similar to those from heavy-duty natural gas engines assuming the same lean-burn technology is employed. Fuel efficiency of propane heavy-duty engines may be slightly lower than that of natural gas engines because propane has a lower octane value, limiting the compression ratio that can be used.

OTHER ALTERNATIVE FUELS AND AFVs

Biodiesel

Vegetable oils have long been recognized as a viable alternative fuel for use in diesel engines. The most popular vegetable oil considered for use as a fuel in the U.S. is soybean oil, although almost any vegetable oil will work, including used cooking oil from restaurants. The properties of vegetable oils are such that they can be used as a fuel in diesel engines with virtually no engine modifications. However, tests have shown that vegetable oils cause rapid degradation of the engine lubricating oil and form fuel-injector deposits that cause severe engine operating problems. By combining vegetable oils with methanol or ethanol, esters are formed and fuel characteristics improve significantly. These esterified versions of vegetable oils have been given the generic label of "biodiesel." Manufacturers of biodiesel have been targeting transit bus fleets for use of a blend typically containing 20% biodiesel with 80% conventional diesel fuel (B20).[24] B20 has been shown to lower smoke, PM, CO, and HC emissions from diesel transit buses, though small increases in NO_x emissions are typical unless fuel-injection timing changes are made. Twin Rivers Technologies has received approval from EPA for using B20 as a "transit bus engine-rebuild technology," under a program designed to reduce emissions from existing diesel buses. Along with using B20, an oxidation catalyst is required, and some engines must retard their injection timing [16]. The primary drawback to biodiesel (before being blended with diesel fuel) is that it costs two to three times as much as diesel fuel.

Electric Vehicles

Strictly speaking, electricity is not an alternative fuel because it is really a form of energy that can be produced from any fuel, but electric vehicles (EVs, or ZEVs [zero emission vehicles]) do represent a means of displacing petroleum fuels used in transportation vehicles. Electric vehicles store their energy in rechargeable batteries that typically can be recharged by connecting them, via a power cord, to a standard electrical outlet.[25] Petroleum fuels are used to generate 10% of the electricity used in New York State, so EVs would represent on average a 90% displacement of petroleum fuels (most EVs appear to be more efficient than petroleum vehicles, which would increase their petroleum-displacement value). NYSERDA

---

[24] These blends of biodiesel and diesel fuel are also frequently referred to as biodiesel.

[25] To fully recharge some EVs overnight, a large-capacity (30-amp, 220-volt) outlet may be required.

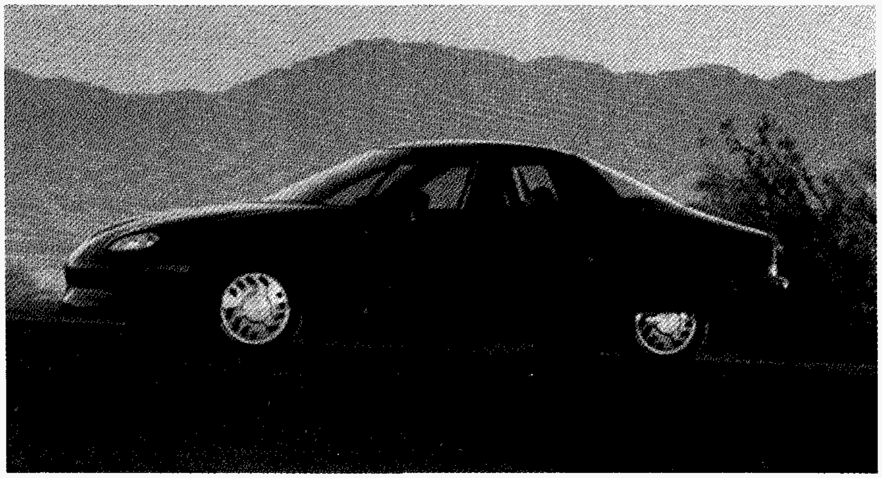
conducted a technology assessment of EVs in New York State, the executive summary of which is included as Appendix M.

New York State EV Regulations. New York State has adopted the original California ZEV regulations for light-duty vehicles, which include a requirement that ZEVs constitute 2% of new-vehicle sales starting in the 1998 model year, and increasing percentages thereafter. California has since changed its ZEV regulations; specific near-term sales targets have been softened, but the sales mandate for 2003 still requires 10% of new-vehicle sales to be ZEVs.

General Motors EV1. On October 15, 1996, General Motors announced that it will begin to offer its EV1 electric passenger car (see Figure 3.19) as a 1997 model through 26 selected Saturn dealerships in Southern California (Los Angeles and San Diego) and Arizona (Phoenix and Tucson). GM's choice of restricted selling areas reflects in part its belief that EVs are best suited to parts of the country with warm climates year-round.

Customers can obtain an EV1 only through a 36-month lease, the capitalized cost of which is $33,995, or about twice the cost of a comparably sized gasoline car. The EV1 is covered by a three-year/36,000 mile "bumper-to-bumper" new car limited warranty. Customers will be carefully screened to ensure their needs are compatible with the operating characteristics of the EV1, and GM will provide special support and

Figure 3.19 GM's EV1 Electric Vehicle



training to the sales and service staffs at the participating dealerships. EV1s will not be leased to individuals who plan to take them outside the restricted market-introduction areas. The required 240-volt Delco Electronics Magne Charge inductive charger is not included in the EV1 lease. It can be purchased for $1,995 or may be leased separately for approximately $50-55 per month through Edison EV, General Motor's Authorized Charger Service Provider. Installation of the charger is additional to these costs. Other vehicle manufacturers have announced plans to introduce EVs in response to ZEV mandates.

EV Capabilities. EVs are expensive, but the best of them can match the acceleration, handling and overall drivability of conventional cars. Range is the major physical drawback. The energy-storage density of the lead-acid batteries used by many EVs typically limits vehicle range to about 40 to 80 miles in city driving, and about 60 to 100 miles under highway conditions, even though most EVs have regenerative braking[26] and other features to increase vehicle operating range. Range limitations are compounded by a lengthy "refueling" process. After an EV has been driven a significant portion of its rated range, four to eight hours are normally required to fully recharge its batteries. Fast recharge equipment, able to accomplish most of the recharging process in about 15 minutes, is presently expensive but further development may reduce the cost and enable this technology to be used to mitigate the impact of EV range limitations. Additional considerations affecting the range issue are that an EV's "fuel gauge" is not as accurate as that of a conventional car, and vehicle performance tends to deteriorate long before the batteries are depleted, factors that reduce drivers' subjective estimates of vehicle range.

A consideration of special importance to drivers in New York State, and other areas that experience significant periods of cold weather, is that all vehicles suffer from range degradation as the temperature drops, as more fuel is consumed to compensate for higher aerodynamic drag, increased rolling resistance, thickening of lubricants, and increased use of auxiliaries. In addition to these effects, EVs must contend with the extraordinary drain placed on the batteries to provide electric-resistance heating to keep windows clear of frost and to warm the passenger compartment (in conventional cars, these heating loads are largely met by using "free" heat available from the engine cooling system). EVs must also contend with decreased battery capacity in cold weather. Lead-acid batteries appear to experience a 20 to 50% decrease in capacity during winter conditions. Most advanced battery types are less affected and cold weather effects can be greatly reduced with proper EV design and thermal management systems (ways to keep the batteries warm).

---

[26] With regenerative braking, energy otherwise absorbed (thrown away as heat) by the brakes is instead used to generate electricity that helps recharge the batteries.

All of this points to the need for improved batteries, plus vehicle design features that properly account for winter driving conditions in the Northeast. Improved batteries, including advanced lead-acid, nickel-metal-hydride, lithium-ion, and other designs, are becoming available, although at a cost premium, and research efforts are under way to develop more efficient ways of providing passenger-compartment heating and cooling. One alternative for space-heating may be to install a small heater fueled by propane or another fossil fuel. Such a device can be made to run very cleanly and would significantly reduce the power drain on the batteries; however, technical definitions in the ZEV mandates may limit this approach.

In the AFV-FDP, NYSERDA purchased an EV built by Solectria Corporation. The vehicle performed acceptably in urban use, with a maximum range under ideal conditions of 40 to 50 miles. The initial set of batteries performed unacceptably in cold weather. Updating the batteries and installing a thermal management system to keep the batteries warm improved the vehicle's cold weather performance, but use of the electric-resistance interior heating system significantly reduced driving range and provided a lower level of comfort than found in conventional vehicles.

<u>Favorable EV Applications</u>. EVs can make good fleet vehicles when operated by drivers such as suburban mail carriers and utility company meter readers who use vehicles in applications where distances are short, stops are frequent, and speeds are low. Also, several transit bus operators and school districts around the U.S. are experimenting with electric buses. While electric buses have limited operating range, just like their light-duty vehicle counterparts, the operating routine of many transit and school buses (fixed local routes that end at the same place each day) makes this less of a detriment. Also, electric vehicles typically have regenerative braking capability, a feature that saves much energy on bus routes that have frequent stops. Regenerative braking has the potential to greatly increase brake lining life (three times or more for transit buses), which would significantly lower maintenance costs. Data are presently insufficient to indicate whether electric buses can compete economically with diesel buses now or in the future.

> <u>New York Power Authority EV Programs</u>
> The Power Authority is demonstrating EVs in a variety of configurations, including buses, cars, and light-duty trucks. For example, the Station Car Program, done in cooperation with Metro-North Railroad and employers in Westchester County, provides seven Solectria Force EVs for use by people commuting via train from New York City to White Plains. These "reverse commuters" use the EVs to complete their trip to suburban work sites. The EVs are equipped with preheaters for winter warming of the passenger compartment while the vehicle is being recharged at the train station.

<u>Emissions</u>. While EVs do not produce emissions, the electricity they use is produced by power plants that do pollute. Taking this into account, EVs may have substantial HC and CO emission-reduction benefits over gasoline-powered cars, and moderate NO_x emission-reduction benefits. EVs may increase particulate matter emissions, but a more in-depth analysis is needed to evaluate the overall impact of the increase. EVs can potentially cause substantial increases in emissions of SO_2, though allowable SO_2 emissions from power plants are capped by the Clean Air Act. Power plants tend to be located in rural areas and this may shift emissions away from large population centers with air-quality problems.

Barriers. Based on a study published by NYSERDA in August 1995, the pessimistic estimates of light-duty EV range and life-cycle operating cost in 2004 are 100 miles and $0.41/mile, respectively. The optimistic estimates are 220 miles and $0.18/mile [17]. These costs represent 140% and 0% increases, respectively, over a comparable gasoline vehicle in 2004. While EVs are projected to have lower fuel costs, their capital costs are projected to be higher and battery-replacement costs may constitute an additional disadvantage.

Summary. EVs can play a role in reducing emissions in congested urban areas and also can be instrumental in reducing the demand for petroleum from transportation vehicles. Operating range, especially in winter conditions, and cost are presently significant EV disadvantages and are being addressed by research programs.

EVs perform acceptably, but their operating range is limited.

Hydrogen and Fuel Cells

Hydrogen is often cited as having potential for use as a transportation fuel and is listed as one of the alternative fuels in the EPACT legislation. Hydrogen is a basic building block of the molecules that make up conventional fuels like gasoline and diesel fuel, as well as alternative fuels like natural gas and methanol, and is made commercially by a reaction process between natural gas and steam. It also can be produced by electrolysis of water. When isolated into its elemental form, hydrogen is a colorless, odorless, highly-flammable gas that can be used directly in conventional engines with the same type of hardware found on CNG and propane vehicles. Much work has been performed documenting the performance and emissions characteristics of hydrogen-fueled engines.

The advantages of hydrogen are that it produces virtually no harmful tailpipe emissions and is a potentially limitless resource, assuming that it is made from electrolysis of water using electricity from renewable resources such as hydropower or solar-powered electric plants. (Hydrogen also can be made from coal, but this process releases large amounts of CO_2, a greenhouse gas.) The primary combustion product of hydrogen is water vapor. Because no carbon is present in the fuel, potential engine emissions are limited to NO_x, possibly some ammonia if combustion takes place under fuel-rich conditions, and possibly some HCs produced from trace amounts of lubricating oil entering the combustion chamber.

The primary drawbacks of hydrogen are its high cost (electrolytic hydrogen costs more than twice as much as an energy-equivalent amount of gasoline) and its low volumetric energy density (Btu/cubic foot), which makes it difficult to store in adequate amounts onboard a vehicle [18]. Figure 3.20 illustrates this point for various storage technologies: if stored as a compressed gas or by techniques using carbon adsorption, metal hydrides, or liquefaction (hydrogen can be liquefied if cooled to -423°F), hydrogen occupies five to 22 times the volume of an energy-equivalent amount of gasoline, without fully accounting for hydrogen's bulkier containers and control systems. By comparison with Figure 3.2, it can be seen that hydrogen also occupies significantly more space than CNG.

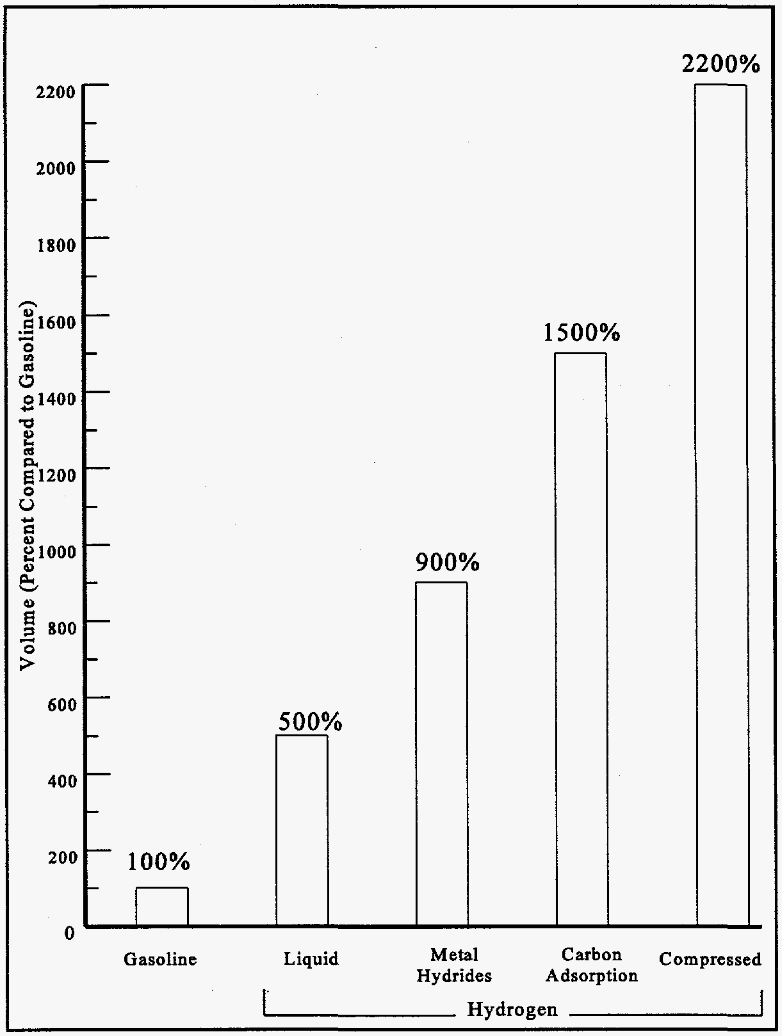
Because of these drawbacks, researchers have focused on using hydrogen in combination with technologies that can achieve higher efficiencies than provided by conventional engines. For example, some researchers have explored using hydrogen mixed with natural gas, in a combination called hythane, in an attempt to increase engine efficiency. By reducing the amount of hydrogen needed, this approach could partially mitigate hydrogen's cost and storage problems.

A more fundamental approach, pursued by NYSERDA in several research projects running in parallel to the AFV-FDP, is to use fuel cells. A fuel cell is an electrochemical device that causes hydrogen to react with oxygen (i.e., air), producing electricity as a direct product and water vapor as the only emission. Fuel cells have the potential to operate at very high efficiency and the resulting electricity then can be used in electric-drive motors without the need to carry large batteries. Research is focused on reducing fuel-cell size and cost, both of which are presently too great compared to conventional technology. Progress is being made and researchers are also looking at ways to run fuel cells on liquid fuels such as methanol, using an auxiliary device called a reformer to separate hydrogen out of the methanol. (Note that a reformer produces CO_2 and possibly other emissions, depending on the input fuel.) This approach would potentially allow a faster or more cost-effective transition to fuel-cell vehicles. Research also is being pursued on direct methanol fuel cells that do not need a reformer.

Hybrid-Electric Vehicles

Hybrid-electric vehicles (HEVs) have a small internal combustion engine driving an electric generator, plus an electric vehicle powertrain, resulting in a vehicle with very low emissions but without the range constraints of an EV. Some observers view HEVs as a transition technology between today's direct-drive fossil-fueled vehicles and tomorrow's efficient and clean battery-electric vehicles. Others view the hybrid

Figure 3.20 Volume Needed to Store Equal Amounts of Energy, Hydrogen Compared to Gasoline (Fuel Only, No Hardware)



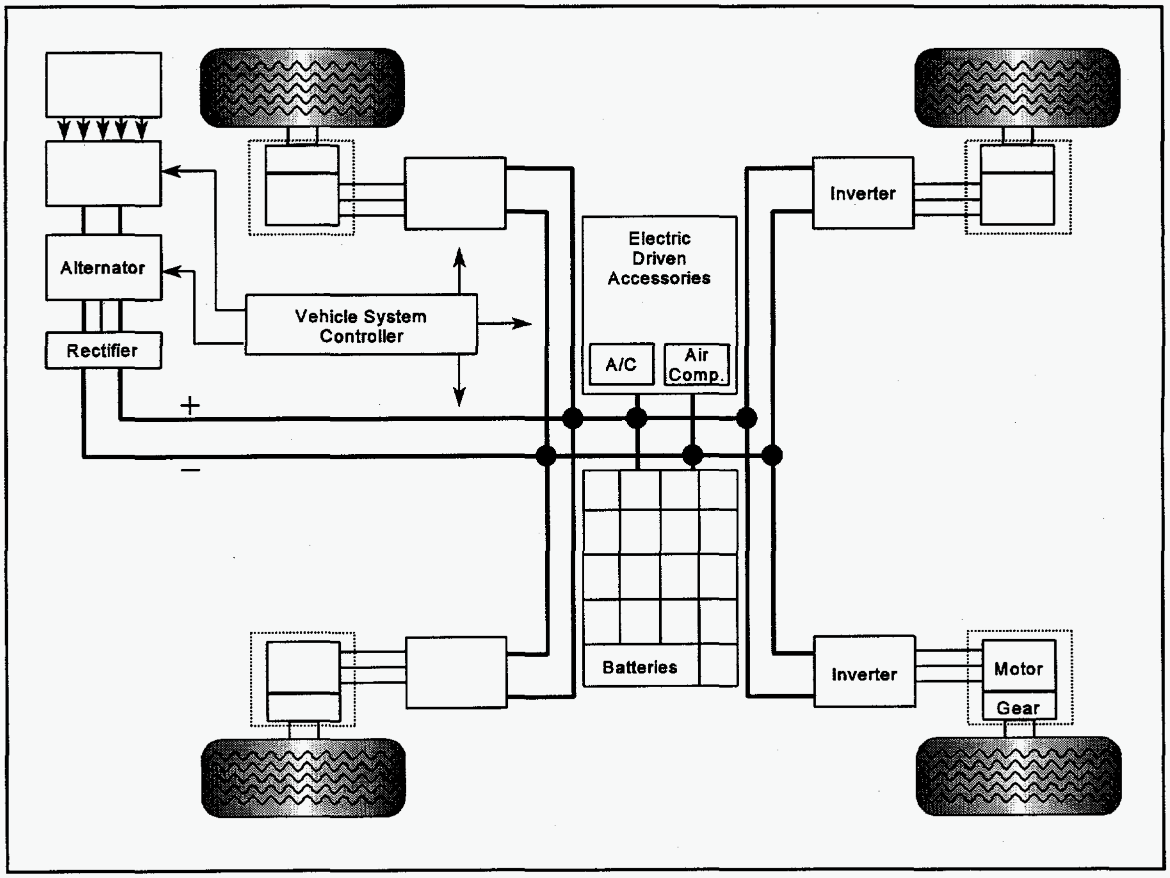
as a viable transportation technology in its own right that may be the preferred technology in some applications previously targeted for battery-electric vehicles. Efficiency and emissions gains observed in prototype HEVs are substantial, and the prices of future vehicles produced in large volumes may well be competitive with conventional vehicles. Moreover, an optimized HEV may have emissions that are actually comparable, on a mile-for-mile basis, with those of a battery-electric vehicle.

This favorable comparison is because recharging battery-electric vehicles requires electricity from power plants that emit pollutants, albeit relatively small amounts per mile of vehicle use. Hybrid vehicles produce their electricity more directly, using on-board power plants operated at their most efficient and cleanest operating points, and make use of regenerative braking to further reduce the amount of fuel being burned, while simultaneously improving operating range and reducing brake system maintenance. Hybrid technology can be applied equally to light-duty passenger vehicles and heavy-duty vehicles, with transit buses being especially well-suited, and may play an important role in broadening the use of alternative fuels. By increasing a vehicle's efficiency, hybrid-electric designs can increase driving range or, alternatively, allow the size of the fuel system to be decreased, thereby helping overcome significant hurdles limiting application of various alternative fuels.

NYSERDA has worked with Orion Bus, Unique Mobility, and General Electric to build and test different types of prototype hybrid-electric transit buses. Orion supplied an Orion II as shown in Figure 3.21 and an Orion VI chassis for two prototypes. Figure 3.22 shows a General Electric powertrain developed for the Orion VI prototype. The Orion II prototype has been lent to several transit properties (in Albany, Niagara Falls, Long Island, Westchester County, New York City, and Ithaca) for evaluation and the hybrid bus concept has proven to be viable. Based on this experience, NYSERDA is assisting manufacturers in developing hybrid-electric trucks, school buses, transit buses, and other hybrid-electric vehicles and components.

Figure 3.21 Orion II Hybrid-Electric Bus

Figure 3.22 Schematic of the Orion VI Hybrid-Electric Bus Powertrain



Section 4
AFV STATUS

AFV TECHNOLOGY STATUS AND VEHICLE COST

The development of alternative-fuel technology has not been uniform across alternative-fuel types. The earliest work focused on alcohol technology, particularly with materials compatibility and ways of coping with cold-start and other engine operating modes substantially affected by the differences in alcohol properties compared to gasoline. But the real breakthrough in alcohol-fuel vehicle technology was the development of fuel sensors that could determine the percentage of alcohol in mixtures of alcohol and gasoline. This development spurred the creation of flexible-fuel vehicles and made alcohol vehicles viable. Further gains in efficiency and emissions are possible with vehicles that use only alcohol fuels, but until an alcohol-fuel-distribution infrastructure is in place, flexible-fuel vehicles will represent the state of the art in alcohol-fuel-vehicle technology. Flexible-fuel vehicle technology may undergo improvements in the future that might enhance efficiency, emissions, durability, and other attributes, but the consensus is that FFVs are technically mature and further gains will be relatively small.

> New York State is a leader in AFV technology.

Natural gas vehicle technology is quickly approaching the same level of maturity. Significant advances have been made in the past few years that have highlighted the efficiency and emissions potential of natural gas vehicles. Heavy-duty engine manufacturers like Cummins are continuing to expand the variety and capabilities of CNG engine product offerings to rival the power, durability, and other desirable attributes of diesel engines, while reducing production of particulates and other key pollutants to extremely low levels. As for light-duty vehicles, the major auto companies are each selling, or have demonstrated the ability to sell, dedicated CNG cars and other vehicles capable of reducing engine exhaust-gas ozone precursors to extraordinarily low levels, and of virtually eliminating evaporative emissions. Propane technology appears to be less mature, but the same technology used with CNG is readily transferable to propane vehicles.

Electric vehicles are nowhere near the same level of development as alcohol, natural gas, or propane vehicle technology. The most urgent need is for improved batteries that can handle the energy-storage density requirements while delivering high power and long life. Other EV components that would benefit greatly from further development include motors and controllers. In the meantime, hybrid-electric vehicle technology has rapidly emerged as a strong contender for urban-vehicle markets and may become cost-competitive with conventional transit buses and urban delivery vehicles.

The technology for using hydrogen in internal combustion engines is fairly well-known. The primary impediment is its cost and the lack of a distribution infrastructure for vehicles. Storing sufficient hydrogen onboard to equal the operating range of conventional vehicles also presents a significant technical hurdle. Hydrogen, however, is the preferred fuel for fuel cell vehicles. Due to their high efficiency, fuel-cell vehicles lessen the severity of these hurdles, and their development may spur implementation of a hydrogen-distribution infrastructure. With additional research, it also may be possible to cost-effectively operate fuel-cell vehicles on methanol and other liquid fuels.

As AFV technology continues to change, the cost of acquiring AFVs also changes. Table 4.1 illustrates typical ranges of costs, based on experiences with acquiring AFVs and conversion equipment in the AFV-FDP.

AFV TECHNOLOGY DEVELOPERS IN NEW YORK STATE

New York State companies have been very active in developing and manufacturing AFVs and AFV components, including equipment needed to establish a fueling infrastructure. NYSERDA has worked with many of these firms to develop products for the AFV market and to pursue economic development opportunities. Table 4.2 provides a partial list of New York State manufacturers active in the AFV arena.

To encourage additional AFV development efforts and manufacturing in the State, the Advanced Vehicle Technology Center (AVTC) has been established at the Griffiss Business and Technology Park in Rome (Oneida County). The AVTC is a not-for-profit organization that resulted from State, federal, and local efforts to provide a centralized facility where AFV technology developers and manufacturers can more easily launch new product initiatives. Several of the companies in Table 4.2 have expressed interest in using the AVTC to begin or expand their AFV businesses.

Gas and electric utilities in the State also have been active in supporting AFV technology development and establishing infrastructure. They have acquired large numbers of AFVs for use in their own fleets and have sponsored many demonstration projects, including co-funding for AFV-FDP activities, to enable other fleet operators to become acquainted with CNG and electric vehicles. In addition, suppliers of LPG/propane have helped with demonstration projects and have made progress towards taking unified action to support research and development efforts.

Table 4.1 Typical Incremental Prices of AFVs

Type of AFV	Incremental Price[1]	
	Without Discounts	Including Recent Discounts
CNG Light-Duty Vehicle Bifuel Conversion	\$3,500 to \$6,500[2]	--
1996 Dedicated CNG Ford Crown Victoria Sedan	\$6,165	\$3,255
1994 Dedicated CNG Dodge Ram Van[3]	\$4,300	--
1996 CNG Bifuel Ford F-Series Pickup	\$6,000 to \$6,400[4]	\$4,780 to \$5,180
1996 CNG Bifuel Ford Econoline Van	\$6,700 to \$10,615[4]	\$4,260 to \$8,175
1996 Ford Taurus M85 or E85 Flexible-Fuel Sedans	M85: \$1,165 E85: \$1,165	M85: \$0 E85: (\$345)[5]
Propane Light-Duty Vehicle Bifuel Conversion	\$2,000 to \$2,500[6]	--
1996 Propane Ford F-Series Pickup	\$3,600 to \$3,700[7]	\$2,380 to \$2,480
Bluebird Dedicated CNG School Bus	\$20,000	--
Dedicated CNG Transit Bus	\$40,000 to \$50,000	--

[1] Prices representative of AFVs available during 1996, or for vehicles acquired earlier as part of the AFV-FDP.
[2] Depends primarily on the amount of CNG storage on the vehicle.
[3] Not available for sale in the 1995 and 1996 model years.
[4] Range due to different CNG tank arrangements.
[5] Ford is pricing its 1997 E85 Taurus at \$345 less than the comparable gasoline Taurus for the first 12,000 sold.
[6] Depends primarily on the amount of propane storage on the vehicle.
[7] Range due to different propane tank arrangements.

Other firms in the State, including engineering and specialty equipment companies, have expanded their capabilities to respond to the challenge of building AFV infrastructure, with its special requirements. Examples are ConVault (Delmar, Albany County), which supplied all the M85 refueling stations along the New York State Thruway as part of the AFV-FDP, and Aurora Technology Corporation (East Aurora, Erie County), which has established itself as a designer and builder of CNG refueling stations.

NEW YORK STATE AFV POPULATION

The number of AFVs in New York State has been growing rapidly over the past few years. At present, there are approximately 200 methanol vehicles operating in the State, composed primarily of flexible-fuel passenger cars, but also including 18 transit buses operating in New York City. There are approximately 2,600 CNG vehicles, including passenger cars, light trucks, and transit buses, on the State's streets and

Table 4.2 Examples of Companies in New York State Providing AFV Products or Services

Company	Location	AFV Product or Service
Advanced DC Motors	Syracuse	Supplier of electric motors for EVs
AFTCO	Jamaica	CNG conversion equipment, installation, and service
Aurora Technology	East Aurora	Fabricates and installs CNG refueling stations
B.F. Goodrich	Norwich	Developing lightweight generator for HEVs
Clean Vehicle Systems	Staten Island	CNG conversion equipment, installation, and service
Clever Fellows	Troy	Developing Stirling engine-generator for HEVs
ConVault	Delmar	Methanol- and ethanol-compatible aboveground tanks
Corning	Corning	Supplier of advanced lead-acid battery components for EVs and HEVs
Cummins Engine Co.	Jamestown	Builds natural gas engines for trucks and buses
DAIS	Fishkill	Developing fuel cell
Delphi (General Motors)	Rochester and Lockport	Developing HEV propulsion systems and fuel cells; supplier of AFV fuel system components
EDO Corporation	Queens	Supplier of CNG products and services
Emerson Power Transmission	Ithaca	Supplier of transmissions for EVs and HEVs
General Electric	Niskayuna and Fort Edward	Supplier of HEV powertrains and ultracapacitors
Lockheed Martin	Johnson City	Supplier of HEV powertrains
Matthews Buses	Ballston Spa	Supplier of CNG school buses
Mechanical Technology Incorporated	Latham	Developing fuel cells and HEV controller
Metropane	Staten Island	CNG conversion equipment, installation, and service
Moda Magnetic	Farmingdale	Supplier of electric motors for EVs and HEVs
Moog	Buffalo	Supplier of LNG refueling nozzles
Nova Bus	Plattsburgh	Developing hybrid-electric transit buses
NYSEG	Binghamton	CNG conversion equipment, installation, and service
Orion Bus	Oriskany	Supplier of CNG and HEV transit buses
Praxair	Tonawanda	Supplier of equipment for storing and handling hydrogen and other gaseous fuels
Reveo	Hawthorne	Developing zinc-air battery for EVs
Tonawanda Truck Repair	Tonawanda	CNG conversion equipment, installation, and service

highways. The number of propane vehicles has been difficult to verify, but is roughly estimated to be between 5,000 and 10,000, with most being light trucks. Only one ethanol vehicle is known to be operating in the State and the population of EVs is estimated to be a few dozen, mostly in demonstration projects.

The infrastructure to serve AFVs is growing, thanks in part to the AFV-FDP. At present, there are 11 methanol-refueling facilities in the State, although only one of these is publicly accessible. There is one ethanol-refueling facility, which serves the City of White Plains municipal vehicles only. Several EV recharging facilities exist dedicated to specific vehicles. There are 47 CNG-refueling facilities in New York State, with 15 of these open to the public, 22 semi-private (public refueling with advance notice), and 10 private. There are about 150 propane dealers in the State equipped to refuel propane vehicles, although the majority of these facilities are not conventional service stations where gasoline is sold.

NEW YORK CITY'S ALTERNATIVE-FUEL PROGRAM

New York City (NYC) has been introducing AFVs into its fleet since the early 1990s. The impetus for using AFVs originated from a recommendation by the City's Alternative-Fuel Vehicles Task Force, composed of representatives from the NYC Department of Environmental Protection and other NYC departments. This recommendation resulted in Local Law 6 of 1991, designed to achieve environmental and economic benefits by introducing AFVs into the City's fleet and encouraging their use in private fleets.

NYC has identified three major benefits to AFVs: (1) reductions in air emissions that are mandated by the federal Clean Air Act and can be achieved more cost-effectively than with other air-pollution-control strategies; (2) reduced dependence on imported petroleum; and (3) economic benefits through the purchase of AFVs and development of supporting infrastructure that will have a multiplier effect on local sales, wages, and tax revenues.

Table 4.3 lists AFVs acquired by New York City. Light-duty natural gas vehicles and methanol FFVs comprise the majority of NYC AFVs. (Because bulk propane storage is prohibited in NYC, propane vehicles are not included.) NYC presently plans to significantly increase the number of AFVs in its fleet and also is encouraging adoption of AFVs into non-City fleets, such as taxis and transit buses. NYC has taken the lead in establishing the New York Metropolitan-Area Clean City Coalition to unify the separate efforts of public and private entities to increase acquisition of AFVs in NYC. The Clean City Coalition plans to coordinate AFV purchasing and develop efficient AFV refueling infrastructure. The Clean City Coalition has set a goal of 36,000 AFVs to be operating in NYC by the end of 1998.

Table 4.3 NYC AFVs in Operation as of 1995

Type of AFV	Total
Light-Duty CNG Conversions	335
M85 Tauruses	121
Electric Vans	5
CNG Refuse-Compactor Trucks	5
CNG Street-Sweeper	1
Methanol Buses	18
CNG Buses	55
Dedicated CNG Vans	53
Totals	593

CLEAN-FUEL TAXI PROGRAM

Approximately 12,000 medallion taxis operate in New York City, accounting for about 10% of all the City's vehicle-miles-traveled and about 35% of the City's mobile-source emissions. To reduce both air pollution and petroleum dependence, a program has been launched to assist the NYC taxi industry in adopting CNG, potentially culminating in CNG-fueled HEVs and other advanced-technology vehicles replacing conventional gasoline taxis.

Although CNG is significantly less expensive than gasoline on a per-gallon basis and the average cab uses more than 7,000 gallons of fuel per year, creating the potential for a market-driven switch to CNG, many complicating factors prevent a rapid switch. Significant barriers include the difficulty in developing a vehicle package that fulfills all the requirements for taxi service, including adequate fuel capacity and the ruggedness to function reliably and cleanly for many miles of driving (it is common for a NYC taxi to accumulate more than 75,000 miles per year, mostly under harsh stop-and-go conditions).

Consequently, State, federal, and local resources are being combined in a multiphase effort to introduce CNG to the taxi market. The NYC Department of Environmental Protection (DEP) has secured federal Congestion Mitigation and Air Quality Improvement (CMAQ) funding to assist in converting up to 700 taxis to CNG. NYSERDA has been assisting DEP by funding a pilot fleet of about 18 CNG taxis to help resolve technical and institutional issues. Also assisting have been the NYC Taxi and Limousine Commission, NYC Department of Transportation, and the local utilities supplying natural gas (Brooklyn

Union and Consolidated Edison). NYSERDA will continue assisting by managing procurement under the CMAQ-funded effort. The program is now under way and is planned to continue at least into 1998, including emissions testing and reporting activities.

Beyond this program, NYSERDA is funding several HEV development efforts that may yield a CNG-fueled HEV taxi suitable for demonstration before the end of the century.

Section 5

GLOSSARY

acetaldehyde	toxic compound in engine exhaust gases; produced from combustion of all fossil fuels—ethanol combustion typically creates higher concentrations because acetaldehyde is an ethanol combustion reaction intermediate
acid rain	rainwater, snow, fog, and other forms of precipitation that contain mild solutions of sulfuric and nitric acids from burning fossil fuels
AFV	alternative fuel vehicle
AFV-FDP	Alternative Fuels for Vehicles Fleet Demonstration Program
ASTM	American Society for Testing and Materials
autoignition temperature	temperature at which a fuel will spontaneously ignite when mixed with air
Avocet®	methanol ignition improver (enables methanol combustion in diesel engines)
AVTC	Advanced Vehicle Technology Center (Rome, NY)
B20	blend of 20-volume-percent vegetable oil or animal fat ester and 80-volume-percent diesel fuel; see biodiesel
bifuel	vehicle with two fuel systems, of which only one can be used at a time
biodiesel	fuel made from vegetable oils or animal fats and used in diesel engines, typically in a blend (e.g., B20) with conventional diesel fuel
Btu	British thermal unit, the energy needed to raise one pound of water one °F
CAAA	Clean Air Act Amendments of 1990
CARB 2 RFG	the second (more stringent) level of reformulated gasoline required to be produced and sold in California
Clean Cities	U.S. Department of Energy program to assist cities in purchasing and using AFVs
clean diesel	diesel fuel modified to achieve lower exhaust emissions; modifications typically include reducing the amounts of sulfur and aromatic hydrocarbons found in conventional diesel fuel
closed-loop	emission control system that adjusts engine operation based on exhaust-gas composition
CMAQ	Congestion Mitigation and Air Quality Improvement (Federal Highway Administration program)
CMSA	Consolidated Metropolitan Statistical Area
CNG	compressed natural gas
CO	carbon monoxide (exhaust emission caused by incomplete combustion)

CO_2	carbon dioxide (a major greenhouse gas produced from combustion of carbon-containing fuels)
conventional fuel	gasoline, diesel fuel, and other fuels derived from crude oil
criteria pollutant	pollutant determined by EPA to be hazardous to human health and subject to EPA regulations.
Cummins	Cummins Engine Company (manufacturer of diesel and alternative-fuel engines)
cylinder	high-pressure storage container for gases
DDC	Detroit Diesel Corporation (manufacturer of diesel and alternative-fuel engines)
dedicated	vehicle with only one fuel system
denaturant	toxic, foul-tasting, or foul-smelling substance added to ethanol to discourage human consumption
DEP	NYC Department of Environmental Protection
DER	discrete emission reduction (credit)
deterioration factor	a factor determined by testing which predicts the increase in emissions over the life of a vehicle
diurnal	refers to evaporative emissions caused by the typical rise and fall of ambient temperature over a 24-hour period
DOE	U.S. Department of Energy
E85	blend of 85-volume-percent ethanol and 15-volume-percent gasoline
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act of 1992
ERC	emission reduction credit
EV	electric vehicle
EV1	General Motor's production electric vehicle
fast-fill	refueling a CNG vehicle in the same amount of time as it would take to refuel an equivalent conventional-fuel vehicle
FFV	flexible-fuel vehicle (vehicle able to use alcohol fuels or gasoline, or any blend of alcohol and gasoline)
formaldehyde	toxic compound in exhaust gases; produced from combustion of all fossil fuels—methanol combustion typically creates higher concentrations because formaldehyde is a methanol combustion reaction intermediate
FTP	Federal Test Procedure (driving cycle used by EPA to certify light-duty vehicles for emissions)
fuel cell	energy-conversion device that produces electricity from hydrogen or fuels that contain hydrogen

full fuel cycle	tracking all inputs and outputs of fuel production and use, from resource through combustion
gasohol	blend of 10-volume-percent ethanol in gasoline
gasoline-equivalent gallon	amount of an alternative fuel that contains the same amount of energy as in one gallon of gasoline
global warming	theory that the average temperature of the earth's atmosphere is increasing
greenhouse gas	gases in the atmosphere, such as carbon dioxide, that trap solar radiation and increase the average temperature of the earth's atmosphere
HC	hydrocarbon emissions; vehicles emit HC from tailpipes (due to incomplete combustion) and from fuel systems (due to evaporation)
HDE	heavy-duty engine
HEV	hybrid-electric vehicle
HVAC	heating, ventilation, and air conditioning
I/M	inspection/maintenance (programs requiring periodic tests to identify vehicles producing excessive emissions)
kPa	kilopascal (unit of pressure equal to about 6.8 psi)
latent heat of vaporization	heat required to change a liquid into a vapor
LEV	low-emission vehicle (California emission standard)
LNG	liquefied natural gas (natural gas turned liquid by cooling to minus 260°F)
lower heating value	the heat given off by combustion minus the latent heat of any water vapor in the exhaust gases
LPG	liquefied petroleum gas (synonymous with propane)
M85	blend of 85-volume-percent methanol and 15-volume-percent gasoline
metal hydride	alloy that can store hydrogen within the alloy's internal structure, at relatively low pressure
mpg	miles per gallon
mph	miles per hour
MSA	Metropolitan Statistical Area
MTBE	methyl tertiary butyl ether (oxygenated additive made from methanol and used in reformulated and oxygenated gasoline)
NAAQS	National Ambient Air Quality Standards (set by EPA)
NMHC	non-methane hydrocarbons (hydrocarbon emissions minus the methane component; provides a better measure of ozone-forming potential because methane does not participate significantly in reactions that produce ozone)

non-attainment	failure of a geographic region to comply with NAAQS
NO_x	oxides of nitrogen (exhaust emission caused by high temperature combustion)
NYC	New York City
NYPGA	New York Propane Gas Association
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
O&M	operating and maintenance (refers to a vehicle's variable expenses, not counting fuel costs)
O_2	oxygen
octane rating	the resistance of a fuel to autoignition, usually expressed as the average of the research and motor tests, or (R+M)/2
OEM	original equipment manufacturer—refers to vehicles and parts produced by a vehicle manufacturer, as opposed to parts produced by another company (aftermarket supplier) for add-on to the vehicle
OPEC	Organization of Petroleum Exporting Countries
open-loop	emission control system that cannot adjust engine operation based on exhaust-gas composition
OPRHP	NYS Office of Parks, Recreation and Historic Preservation
Orion	Orion Bus Industries, Inc. (bus manufacturer)
oxygenated gasoline	gasoline to which oxygen-containing components, such as alcohols or ethers, have been added to reduce carbon monoxide and other emissions
ozone	an atmospheric gas that, at ground level, is considered an air pollutant and is created from reactions between vehicle emissions in the presence of sunlight
PM	particulate matter (exhaust emission; diesel engines produce large quantities of PM)
PM-10	particulate matter with mean diameter less than 10 microns
psi	pounds per square inch (unit of pressure)
reformulated gasoline	gasoline that has been specially formulated to reduce exhaust emissions
regenerative braking	in an electric or hybrid electric vehicle, energy otherwise absorbed (thrown away as heat) by the brakes that is instead used to generate electricity that helps recharge the batteries
Reid Vapor Pressure	vapor pressure of liquid fuels at 100°F; higher values indicate fuels that vaporize easily, which may help engine performance but can increase emissions
running losses	gasoline vapors released from a vehicle's fuel system when the engine is running
scf	standard cubic foot; basic unit of measure for natural gas

SIP	State Implementation Plan (required by EPA; identifies actions and programs that a state plans to implement to control emissions within its boundaries)
slow-fill	refueling a CNG vehicle over several hours; allows use of less-expensive refueling equipment
smog	visible haze caused by air pollution
SO_2	sulfur dioxide (exhaust emission)
Solectria	Solectria Corporation (electric vehicle manufacturer)
TLEV	transitional low-emission vehicle (California emission standard)
toxics	any air pollutant that may cause cancer or other serious health problems; EPA-defined examples of toxics from conventional fuels include benzene, formaldehyde, acetaldehyde, and 1,3-butadiene
ULEV	ultra low-emission vehicle (California emission standard)
Unique Mobility	Unique Mobility, Inc. (electric and hybrid-electric vehicle component supplier)
VOC	volatile organic compound (exhaust and evaporative emissions; synonymous with HC)
wear metals	trace amounts of metal that rub off engine parts during normal use
ZEV	zero-emission vehicle (California emission standard; synonymous with electric vehicle)

Section 6

REFERENCES

1. American Lung Association, Breath in Danger II, 1993.

2. Jääskeläinen, H.E. and J.S. Wallace, "Performance and Emissions of a Natural Gas Fueled 16 Valve DOHC Four-Cylinder Engine," SAE Paper No. 930380, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, 1993.

3. "Alternatives to Traditional Transportation Fuels - 1994 - Volume 2: Greenhouse Gas Emissions," U.S. Department of Energy, Energy Information Administration, Report No. DOE/EIA-0585(94)/1, February 1996.

4. Wang, M.Q., "Development and Use of the GREET Model to Estimate Fuel-Cycle Energy Use and Emissions of Various Transportation Technologies and Fuels," Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, March 1996.

5. Grant, Dr. T.J., et. al. (EBASCO Services Inc.), "Safety Analysis of Natural Gas Vehicles Transiting Highway Tunnels," NYSERDA Report 90-2, August 1989.

6. Grant, Dr. T.J., et. al. (EBASCO Services Inc.), "Safety of Natural Gas Dual-Fueled Vehicles," Addendum to NYSERDA Report 90-2, January 1991.

7. "Alternatives to Traditional Transportation Fuels - 1994 - Volume I," U.S. Department of Energy, Energy Information Administration, Report No. DOE/EIA-0585(94)/1, February 1996.

8. ASTM D5797 - Specification for Fuel Methanol M70-M85 for Automotive Spark-Ignition Engines, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

9. ASTM D5798 - Specification for Fuel Ethanol Ed70-Ed85 for Automotive Spark-Ignition Engines, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

10. Cowart, J.S., et al., "Powertrain Development of the 1996 Ford Flexible Fuel Taurus," SAE Paper 952751, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096-0001, 1995.

11. The U.S. Department of Energy Biofuels Feedstock Development Program, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN, 37831-6422.

12. "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector; Technical Report Fourteen: Market Potential and Impacts of Alternative Fuel Use in Light-Duty Vehicles: A 2000/2010 Analysis," U.S. Department of Energy Office of Policy and Office of Energy Efficiency and Renewable Energy, DOE/PO-0042, January 1996.

13. Kamel, Mostafa M. (Cummins Engine Company, Inc.), "The B5.9G Gas Engine Technology," SAE Paper No. 952649, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, 1995.

14. Miller, Stanley P. (Detroit Diesel Corp.), GM/NYC Methanol Bus Program Final Report, unpublished, May 1992.

15. "Propane Powered Heavy Duty Trucks in Production," CATF Review, Issue No. 24, January 1996. Published by BCRI, 3650 Wesbrook Mall, Vancouver, BC, Canada V65 2L2.

16. Federal Register, Vol. 61, No. 205, Tuesday, October 22, 1996, pp. 54790-54798.

17. Booz•Allen & Hamilton, Inc. Zero-Emission Vehicle Technology Assessment prepared for the New York State Energy Research and Development Authority, NYSERDA Report 95-11, August 1995.

18. "Hydrogen Program Plan, FY 1993-FY 1997," National Renewable Energy Laboratory, Report No. DOE/CH10093-147, DE92010556, June 1992.