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16. Abstract

New legislation and significant advancements in alternative fuels development have generated considerable interest in costs and benefits associated with vehicle technology research and development. Further, interest in alternative fuels developed as a possible way to enhance energy security in the United States. The Clean Air Act Amendments (CAAA), passed during the administration of President George W. Bush, introduced the need to examine the future use of alternative fuels as well as the role of traditional vehicle fuels.

The primary objective of the study was to conduct a case study of a large-scale fuel conversion project to assess selected costs and related issues. Several approaches were used to document the project. An inventory of public transit agencies engaged in demonstration projects involving alternative fuels as conducted with representative sample of large public transit systems in the nation. Included in the survey were questions pertaining to fuel supply arrangements, fuel reserve storage requirements and/or deficiencies; future plans for managing energy resources and costs associated with fuel conversion/alternative fuels use -- whether planned or currently in operation. The case study approach was used to document the methodological and logistical problems encountered during the course of projects involving alternative fuels use compared with a control sample using diesel fuel. Monthly status reports on the alternative fuel project included data on accumulated mileage, road calls/unscheduled maintenance, fuel consumption, fuel cost per mile, alternative fuel purchases, schedule of activities, personnel, safety, and diesel emission test results. The data collected indicate several conclusions and future implications about technical and safety issues associated with the testing and use of liquefied natural gas (LNG).

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A SURVEY OF COSTS ASSOCIATED WITH ALTERNATIVE FUELS DEVELOPMENT: A CASE STUDY

by

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DISCLAIMER

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The author gratefully acknowledges the contributions of several individuals. The General Manager of Houston METRO, Robert MacLennan provided support for the project through his consent to allow us to work with project managers of the Liquefied Natural Gas (LNG) alternative fuels project. The project team was lead by Russell H. Pentz, Assistant General Manager of Maintenance for The Metropolitan Transit Authority of Harris County (Houston METRO) who served as Project Monitor during the course of the entire research. He was assisted by George A. Herman, Deputy Assistant General Manager of Maintenance. Monthly reports of activities pertaining to the alternative fuels project were sent to us on a regular basis for use in the data collection phase of the project.

Two graduate students in the Department of Transportation Studies at Texas Southern University, Mohammed Hamid and Ramesh Narayanappa, conducted extensive literature searchers to assess the state-of-the-art on Liquefied Natural Gas (LNG) and related alternative fuels. All drafts of the report were typed by Sallie M. Harrell, administrative secretary in the Center for Transportation Training and Research at Texas Southern University.

The author also recognizes the support provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center.

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ABSTRACT

New legislation and significant advancements in alternative fuels development have generated considerable interest in costs and benefits associated with vehicle technology research and development. Further, interest in alternative fuels developed as a possible way to enhance energy security in the United States. The Clean Air Act Amendments (CAAA), passed during the administration of President George W. Bush, introduced the need to examine the future use of alternative fuels as well as the role of traditional vehicle fuels.

The primary objective of the study was to conduct a case study of a large-scale fuel conversion project to assess selected costs and related issues. Several approaches were used to document the project. An inventory of public transit agencies engaged in demonstration projects involving alternative fuels was conducted with a representative sample of large public transit systems in the nation. Included in the survey were questions pertaining to fuel supply arrangements, fuel reserve storage requirements and/or deficiencies; future plans for managing energy resources and costs associated with fuel conversion/alternative fuels use — whether planned or currently in operation. The case study approach was used to document the methodological and logistical problems encountered during the course of projects involving alternative fuels use compared with a control sample using diesel fuel. Monthly status reports on the alternative fuel project included data on accumulated mileage, road calls/unscheduled maintenance, fuel consumption, fuel cost per mile, alternative fuel purchases, schedule of activities, personnel, safety, and diesel emission test results. The data collected indicate several conclusions and future implications about technical and safety issues associated with the testing and use of liquefied natural gas (LNG).

EXECUTIVE SUMMARY

Significant advancements in alternative fuels development have generated considerable interest in costs and benefits associated with vehicle technology research and development. With increasing concerns about the environmental pollution and the vast amount of petroleum consumption, there has been an interest in the development of new sources of energy for vehicles and new technologies. Most of the petroleum consumed in the United States was in the transportation sector. The transportation sector accounts for approximately two-thirds of all petroleum use and roughly one-fourth of total energy consumption in the United States.

New legislation and policies have been introduced, in order, to reduce the nation's dependence on petroleum fuels in the transportation sector. The Energy Policy Act of 1992 (EPACT) requires certain fleet vehicles to operate on alternatives to petroleum fuels. The Clean Air Act of 1990 (CAA) requires individual states to implement clean-fuel fleet programs. The Congressional Office of Technology Assessment (OTA) released a report in August of 1991 describing those energy strategies the United States would follow over the next 25 years.

In response to these mandates, many states and local agencies have implemented laws and incentives to promote the increased use of alternatives to gasoline and diesel fuels. Alternative fuels legislation at the state and federal level has sparked considerable debate about fuel supply and demand and overall costs for modifying vehicles so that alternative fuels can be used. The landmark Clean Air Legislation passed by the State of Texas in June, 1989 imposed two fundamental requirements upon state agencies, school districts, and public transit authorities:

- No such entities will be permitted to purchase or lease vehicles which are incapable of utilizing clean-burning alternative fuels after September 1, 1991. And,

- Thirty percent of all effected fleets will be alternatively-fueled by September 1, 1994. This percentage will increase incrementally to ninety percent by 1988 if the Texas Air Control Board determines that the program is having a positive effect upon the environment.

The state did not and does not recognize highly refined or "super clean diesel" as an alternative fuel.

In 1991, the transportation sector alone consumed 21.4 quads of petroleum fuels, accounting for 65.4 percent of total petroleum consumed in the United States, according to a report prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy in March, 1993. Executive Order 12759 of April 17, 1991, Federal Energy Management, Section 11, "Procurement of Alternative Fueled Vehicles" requires that the "maximum number practicable of vehicles acquired annually are alternative fueled vehicles." The guidance document developed by the Department of Energy (DOE) with interagency consultation established goals for the Federal procurement of alternative fueled vehicles (AFVs) (Figure 1.1). In Figure 1.2, the breakdown of Federal agency request for AFVs in the 1993 fiscal year by vehicle type and fuel type is exhibited.

The usage of alternative bus fuels is another important item of discussion. Van Wilkins (1994:7) reveals that the "Clean Air Act, with its increasingly strict limits on emissions, almost certainly means the end of the two-stroke diesel era. The author also advises that "increasingly strict emission standards affect 80% of transit buses in the United States, operating in 49 of the largest metropolitan areas. Four types of emissions are of concern, including nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM).

Two types of emissions, NO_X and PM standards, have been progressively reduced since 1988. By 1988, new transit bus engines must be certified by the Environmental Protection Agency (EPA) or the California Air Resources Board (CARB) to have NOx emissions not exceeding 4.0 grams per brake horsepower-hour and a PM level of .05 g/bhp-hr. for diesel engines. PM is the most visible element in bus exhausts. Its reduction has a beneficial effect from the standpoint of public perception, according to Wilkins (1994).

Natural gas has proven to be the most popular alternative fuel choice. At the end of 1993, fifty-nine (59) operators in the United States and Canada reported a total of 899 transit vehicles (including buses and vans) using either natural gas or a combination of natural gas and diesel or gasoline. Natural gas engines can be configured to burn only natural gas, or to burn diesel or gasoline as well. Wilkins (1994:9) indicates that mixtures of natural gas and diesel can be burned, although much higher

Figure 1.1
Target Acquisition of Alternative Fuel Vehicles for Federal Fleets

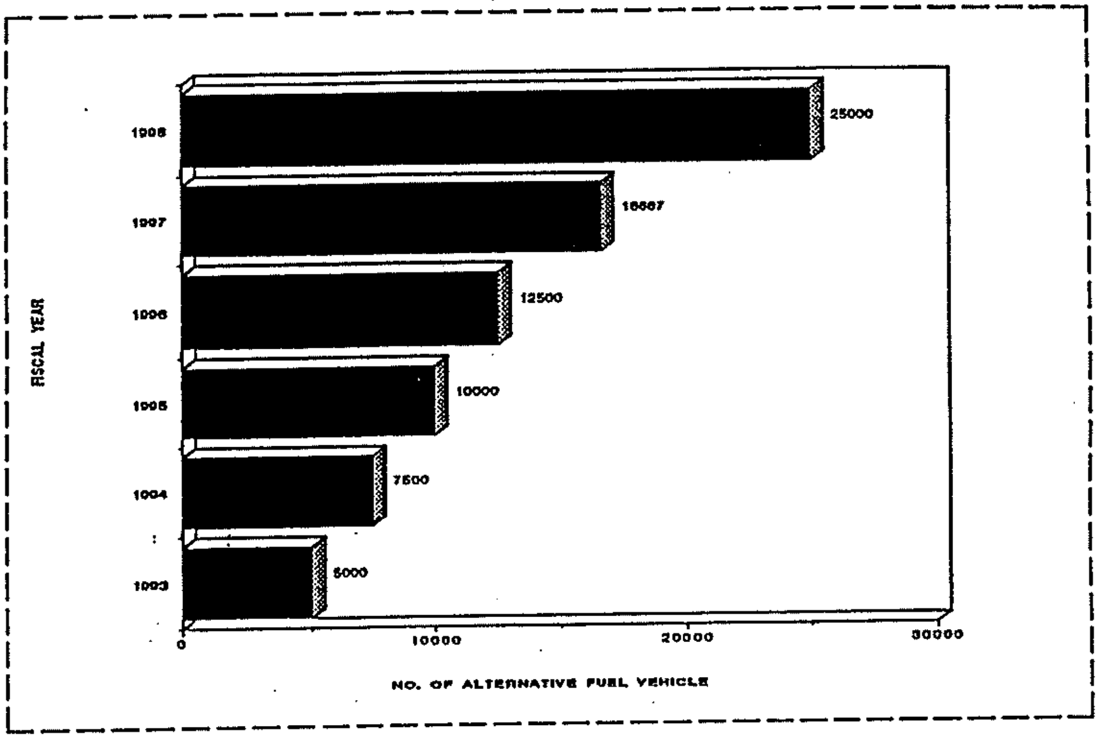
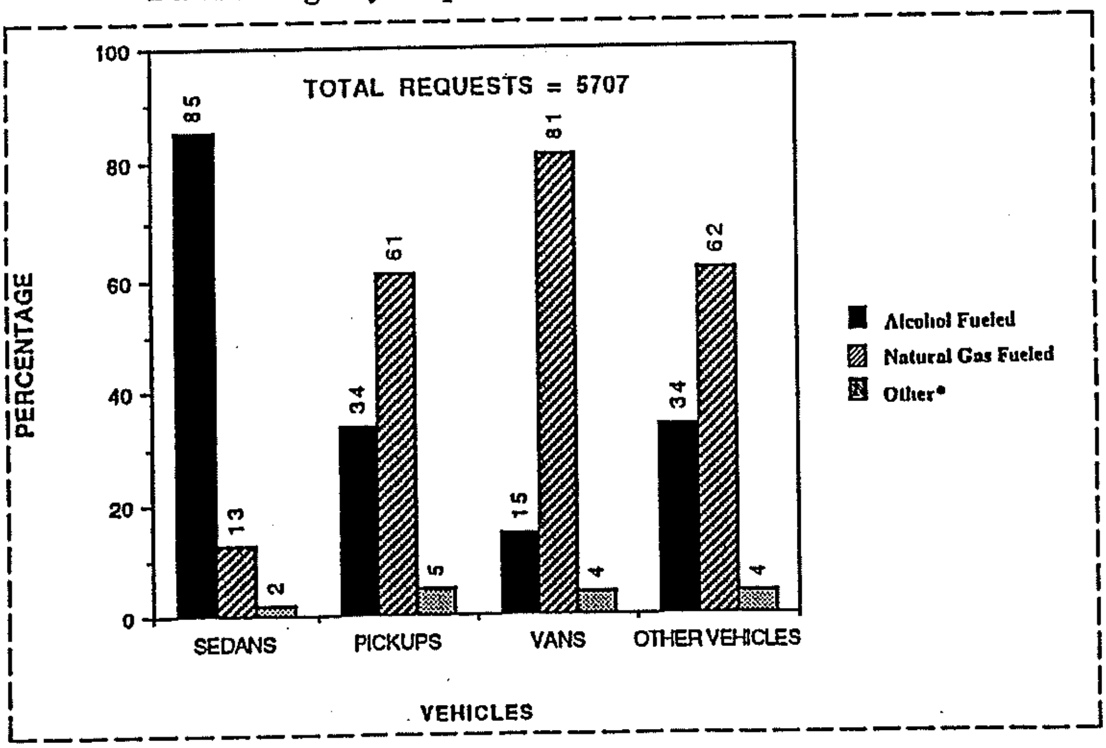


Figure 1.2
FY 1993 Agency Requests for Alternative Fuel Vehicles



compression ratios are required than the spark-ignited natural gas technology. Issues of safety and cost associated with fuel conversion and utilization surface when consideration is given to transit bus fuels technology.

This study was designed to examine both costs and benefits associated with one fuel conversion project involving liquefied natural gas (LNG) and compare the findings with several other alternative fuels that are being used for transportation purposes. The primary objective of the study was to conduct a case study of a large-scale fuel-conversion demonstration project to assess selected costs and related issues. Several approaches were used to document the successful demonstration project and its results. An inventory of public transit agencies engaged in demonstration projects involving alternative fuels was conducted with a representative sample of public transit systems in the nation. Included in the survey were questions pertaining to fuel supply arrangements, fuel reserve storage requirements and/or deficiencies; and future plans for managing energy resources and fuel conversion/alternative fuels projects planned or in operation.

The results of the project described draw heavily on the monthly status reports on alternative fuels of the Metropolitan Transit Authority of Houston and Harris County for the period, 1991-1992. Some key factors have been identified by previous authors as useful tools in determining fuel conversion costs (See: Booz, Allen & Hamilton, Inc., 1991). These conversion factors include: Fuel use, fuel and fueling facility costs, maintenance facility modifications capital costs, and vehicle costs. Data for this study were analyzed within the framework of the economic impact of the switch to alternative fuels.

A summary of the major findings follows:

- When compared with other fuels, natural gas appears to be very popular among alternative fuels.

- Studies indicate several factors, such as air quality benefits, the need to develop technologies to ensure energy independence in the United States, compliance requirements of the legislative mandate under the Clean Air Act Amendments of 1990, safety, the availability vs. lack of availability of an adequate supply of a particular alternative fuel, safety, and the challenges associated with the involvement with a new technology, influenced transit agencies' decisions to use alternative fuels.

- Major problems encountered by transit agencies involved in the utilization of alternative fuels pertained to high costs, technical difficulties in implementing alternative fuels programs, and the lack of industry maturity.

- Despite the problems experienced by transit agencies and other users of alternative fuels, there is the prevailing belief that they can be solved.

- There are disadvantages in the daily use of alternative fuels. Previous studies, including the findings of this research, suggest that higher costs, increased complexity, poor range, longer fueling time, lower efficiency, off-site fueling time, lower efficiency, and limited fuel suppliers are primary disadvantages.

- Several findings surfaced from the case study of the Liquefied Natural Gas (LNG) fuel conversion project of Houston METRO. Preliminary data indicate that the LNG combines the low operating cost of natural gas with the on-board storage density of a liquid fuel. Engine and fuel system reliabilities appear to be approaching an acceptable level.

A SURVEY OF COSTS ASSOCIATED WITH ALTERNATIVE FUELS DEVELOPMENT: A CASE STUDY

I. INTRODUCTION AND BACKGROUND

Increasing concerns about the environment and the nation's dependence on petroleum from unstable areas of the world have hastened the development of new domestic sources of power for vehicles and new vehicle technologies. America continued to consume more than one-fourth of the world's petroleum in 1992. Domestic crude oil production, which has been declining every year from 1985 to 1990 rose in 1991, then fell to a new all-time low of 7.15 million barrels per day in 1992. While domestic crude oil production has declined 20.3% from 1985 to 1992, the amount of crude oil imported has increased 89% in that time period to meet the domestic demand (*Transportation Energy Data Book,* 14, May, 1994).

Most of the petroleum consumed in the United States was in the transportation sector. The transportation sector accounts for approximately two-thirds of all petroleum use and roughly one-fourth of total energy consumption in the United States. A virtual one-to-one relationship exists between gasoline consumption and America's increased use of imported oil. While transportation depends primarily on petroleum, the residential and commercial sector depends heavily on electricity. Tables in the Appendices illustrate transportation energy consumption and the fuels used. They further show that any effort to decrease our dependence on oil hinges on reducing its use in transportation (*Report by Argonne National Laboratory,* p. 2, 1994).

America spends approximately $60 billion per year to import nearly 50% of its oil. These imports are expected to grow nearly 70% by the end of the decade. Domestic oil production has drastically declined, according to a report by the Argonne National Laboratory (1994). A half-million jobs were lost due to this decline. Domestically produced alternative fuels have the potential to reduce the trade deficit, create jobs, and promote economic activity.

In order to reduce the nation's dependence on petroleum fuels in the transportation sector, new legislation and policies have been introduced in the interest of speeding the use of alternatives to conventional gasoline and diesel fuels. The Energy Policy Act of 1992 (EPACT) requires certain fleet vehicles to operate on alternatives to petroleum fuels. The 1990 Clean Air Act (CAA) requires individual states to implement clean-fuel fleet programs. In response to these mandates, many state and local agencies have implemented laws and incentives to promote the increased use of alternatives to gasoline and diesel fuel.

New legislation and significant advancements in alternative fuels development have generated considerable interest in costs and benefits associated with vehicle technology research and development. Considerable interest in alternative fuels developed as a possible way to enhance energy security in the United States following the oil supply and price shocks during the last several decades. Proposals to amend the Clean Air Act were introduced by the Bush administration in June, 1989. Included in the legislation were amendments to the 1963 Clean Air Act. The legislation, signed by the President in November, 1990, affected future use of alternative fuels as well as the role of traditional vehicle fuels.

The Clean Air Act Amendments (CAA) require fleet use of alternative fuels and the manufacture of alternative fuel vehicles. Concomitant with the federal initiative were two bills enacted by the Texas legislature - SB 740 and SB 769 - that encouraged the use of alternative fuels in various vehicles in the state. Public school districts and state agencies are covered by SB 740. Local government fleets and private fleets are covered by SB 769. Public transportation agencies are affected by requirements in both bills.

Both bills passed by the Texas legislature describe an alternative fuel vehicle as a vehicle capable of using compressed natural gas (CNG) or other alternative fuels which result in comparably lower emissions of oxides of nitrogen, volatile organic compounds, carbon monoxide, or particulates or any combination thereof (SB 740 and SB 769).

The Texas Air Control Board (TACB) has proposed rules that define what fuels qualify as alternative fuels, and they currently include the following: natural gas, liquefied petroleum gases (LPG or propane), electricity (typically battery-powered vehicles).

The legislation included deadlines for achieving fleet mix of alternative fuel vehicles in public fleets of affected organizations. By September 1, 1994 the fleet must consist of 30% or more alternative fuel vehicles. This percentage increases to 50% in two years (September 1,1996) and 90% after four years (September 1, 1998). The 1998 deadline applies only if the Texas Air Control Board determines that the program has been effective in reducing total annual emissions in the organizations' area (school district, transit authority jurisdiction).

Other provisions set forth in the alternative fuels legislation address equipment and refueling facilities and affected entities. Senate Bill 740 authorizes affected organizations to purchase or lease equipment and refueling facilities. The organizations can be given or loaned this equipment by suppliers and, in turn, suppliers are allowed to recoup these costs through fuel charges. Senate Bill 769 relates to the adoption of certain regulations to encourage and require the use of natural gas and other alternative fuels.

Recent developments in Texas threaten to delay implementation of emissions testing imposed by the Texas Natural Resource Conservation Committee (TNRCC). A Senate Special Committee on Emissions and Clean Air held public hearings to determine the extent to which the I/M 240 testing plan was the best one to be implemented in clean air non-attainment areas designated by the Environmental Protection Agency (EPA). The non-attainment areas in Texas include: Houston-Galveston, Beaumont-Port Arthur, Dallas-Fort Worth, and El Paso. At the conclusion of the public hearings a "Texas Plan" to deal with the issues will be drafted into Senate Bill 178 for consideration by the Texas Legislature.

1.1 The Energy Policy Act of 1992

The Energy Policy Act (EPACT) was signed into law in 1992. The provisions extended beyond the Clean Air Act in terms of alternative fuels promotion. For instance, EPACT sets earlier deadlines than the Clean Air Act. Federal fleet purchases required by EPACT were scheduled to begin in 1993, but the Clean-Fuel Vehicles program in the Clean Air Act was not scheduled to begin until 1998. Another significant requirement of EPACT is the exclusion of reformulated gasoline and diesel. Instead, it focuses on alternatives or replacements for petroleum based fuels.

Provisions under the Energy Policy Act support the Texas alternative fuels legislation. To this end, it adds momentum to a strong alternative fuels program. EPACT promotes use of alternative fuels (AFs) and vehicles (AFVs) by a combination of fleet mandates and the provision of tax incentives. The intent of the legislation is to reduce motor fuel consumption by 10 percent by the year 2000 and by 30 percent by 2010 (***Alternative Fuels Transportation Briefs, No. 1-7, July, 1993***).

The findings of this study will provide valuable information to those decision makers interested in cost effectiveness and economic efficiency measures as they relate to energy supply and demand. The aim of this study is to enhance efforts to develop strategies for increasing energy efficiency and for reducing the nation's dependence on imported oil. EPACT provides federal incentives that encourage increasing the use and development of alternative fuels.

1.2 Background of the Study

The landmark Clean Air Legislation passed by the State of Texas in June, 1989 imposed two fundamental requirements upon state agencies, school districts, and public transit authorities:

- No such entities will be permitted to purchase or lease vehicles which are incapable of utilizing clean-burning alternative fuels after September 1, 1991. And,

- Thirty percent of all effected fleets will be alternatively-fueled by September 1,1994. This percentage will increase incrementally to ninety percent by 1988 if the Texas Air Control Board determines that the program is having a positive effect upon the environment.

The State did not and does not recognize highly refined or "super clean diesel" as an alternative fuel.

Alternative fuels legislation at the state and federal level has sparked considerable debate about fuel supply and demand and overall costs for modifying vehicles so that alternative fuels can be used. Another issue relates to the question of reducing future vehicle emissions through the use of alternative fuels. This study is designed to examine both costs and benefits associated with one fuel conversion project involving liquefied natural gas (LNG) and compare the findings with several other alternative fuels that are being used for transportation purposes.

1.3 Analysis of Energy Strategy

The Congressional Office of Technology Assessment (OTA) released a report in August of 1991 describing those energy strategies the United States would follow over the next 25 years. The report presents an overview of choices open to energy policy makers and the role that technology can play. "Energy Technology Choices: Shaping Our Future," reveals that the three greatest challenges facing energy policy makers are easing emissions of carbon dioxide, assuring a long-term supply of reasonably priced, convenient fuels, and protecting the nation against disruptions of petroleum imports. Energy policy is equally important to the three fundamental national goals of a healthy economy, clean environment, and security.

Alternative fuels that are of primary interest, according to the report by OTA, are: Reformulated gasoline, alcohol fuels — methanol and ethanol, compressed or liquefied natural gas, hydrogen and electricity. Each of these fuels has advantages and disadvantages. Aside from fuel cost, the major barrier cited by experts in the field is the need to compete with the highly developed technology and massive infrastructure that exist to support the production, distribution, and use of gasoline as the primary fleet fuel. Concerns about the range and performance of vehicles that use alternative fuels are also barriers to public acceptance. (*The Clean Fuels Report,* September, 1991:2).

Alternative Fuels Statistics

In 1991, the transportation sector alone consumed 21.4 quads of petroleum fuels, accounting for 65.4 percent of total petroleum consumed in the United States, according to a report prepared by the Oak Ridge National Laboratory for the U. S. Department of Energy in March, 1993. Citing alternative fuels statistics, the report indicated that " with decreases in domestic oil production and rising demand, the amount of imported crude oil and petroleum products has increased at an average rate of 6.8 percent per year since 1985." The statistics also indicate that 47 percent of the petroleum consumed in the United States in 1991 was imported. The data suggest that addressing the nation's dependence on petroleum will require reducing independence of the transportation sector on petroleum fuels (Davis and Strang, 1993: pp. 5-1).

Executive Order 12759 of April 17, 1991, Federal Energy Management, Section 11, "Procurement of Alternative Fueled Vehicles" requires that the "maximum number practicable of vehicles acquired annually are alternative fueled vehicles." The guidance document developed by the Department of Energy (DOE) with interagency consultation established goals for the Federal procurement of alternative fueled vehicles (AFVs) (Figure 1.1). The breakdown of Federal agency requests for AFVs in the 1993 fiscal year by vehicle type and fuel type is shown in Figure 1.2.

Figure 1.1
Target Acquisition of Alternative Fuel Vehicles for Federal Fleets

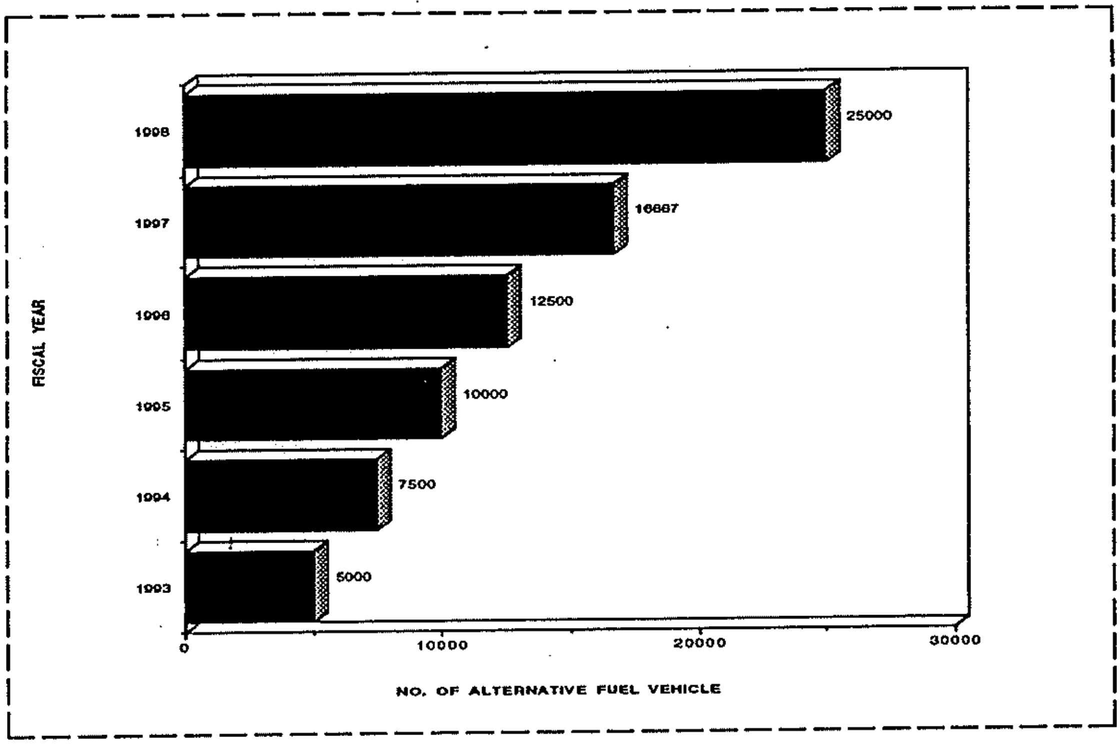
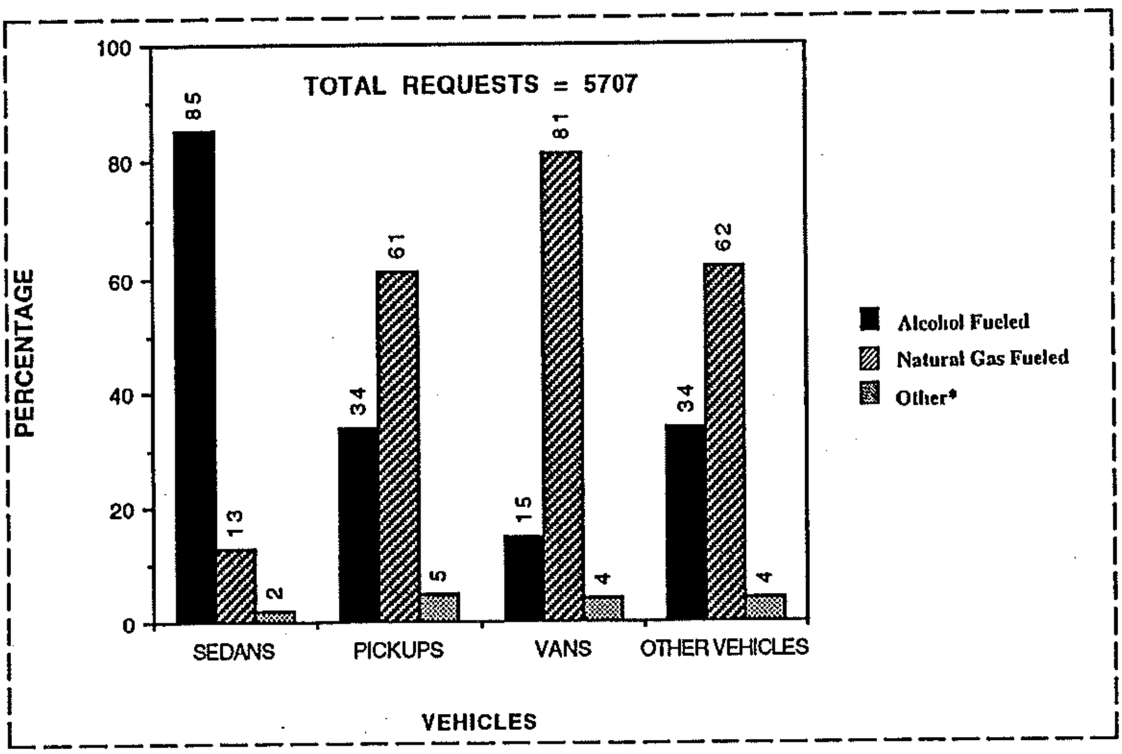


Figure 1.2
FY 1993 Agency Requests for Alternative Fuel Vehicles



One of the major concerns permeating the transportation industry is the adverse impacts of conventional fuels on the environment. Conventional petroleum fuels in motor vehicles are among the major contributors to environmental pollution around the world. Typically, motor vehicles emissions account for 30 to 50 percent of urban hydrocarbon, 80 to 90 percent of carbon monoxide and 40 to 60 percent of nitrogen oxide emissions. Alternative and reformulated fuels may offer the potential to reduce these pollutants significantly. (Davis, Strang, and Hadden, 1993).

Because of increasing concerns about environmental pollution and the growing U. S. dependence on petroleum, policy-makers began to search for ways of diversifying energy sources by switching from conventional to alternative and reformulated fuels. The Clean Air Act Amendments of 1990 (CAAA), as previously indicated, include programs for oxygenated gasoline and for reformulated gasoline (RFG). With the passage of the CAAA, environmental regulations have reached a level of prominence relative to defining product composition and performance, influencing technology, changing consumer expectations of performance, and determining the feasibility of various production and supply options.

Alternative Bus Fuels

A recent article in *Transit Connections* (September, 1994) provides an analysis of alternative fuels for buses. Van Wilkins (1994: 7) reveals that the "Clean Air Act, with its increasingly strict limits on emissions, almost certainly means the end of the two-stroke diesel era. The impact of this legislation on the four-stroke diesel is still an open question." The author further advises that "increasingly strict emission standards affect 80% of transit buses in the United States, operating in 49 of the largest metropolitan areas. Four types of emissions are of concern, including nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM).

Two types of emissions, NOx and PM standards, have been progressively reduced since 1988. By 1998, new transit bus engines must be certified by the Environmental Protection Agency (EPA) or the California Air Resources Board (CARB) to have NOx emissions not exceeding 4.0 grams per brake horsepower-hour and a PM level of .05 g/bhp-hr. for diesel engines. PM is the most visible element in bus exhausts. Its reduction has a beneficial effect from the standpoint of public perception, according to Wilkins (1994).

Natural gas has proven to be the most popular alternative fuel choice. At the end of 1993, fifty-nine (59) operators in the United States and Canada reported a total of 899 transit vehicles (including buses and vans) using either natural gas or a combination of natural gas and diesel or gasoline. The trend toward natural gas utilization continues to grow. Previous research indicates that natural gas provides reduced emissions and meets 1988 standards. As previously indicated, there is an abundant supply of natural gas, lessening dependence in petroleum from the Middle East. Texas, a major producer, has mandated that only natural gas will be used in transit buses. In Canada, low emissions from natural gas are factors in the scale-back of zero-emissions electric trolley bus service in Toronto and Hamilton.

Despite the abundant domestic supply of gasoline and the low emissions attributed to it, natural gas is still in the evaluation stage, with some buses in service in selected cities throughout the United States and Canada. In the United States, the operators of natural gas vehicles are in the cities of Austin, El Paso, Cleveland, Fort Worth, Houston, Sacramento, Santa Fe, Tacoma, and Tucson. Canadian cities using natural gas vehicles include: Hamilton, Mississauga, and Toronto. These are the only natural gas vehicle operators with fleets of more than ten vehicles. Houston has a fleet of over 250 vehicles, and Fort Worth and Sacramento have fleets of over 50 natural gas buses.

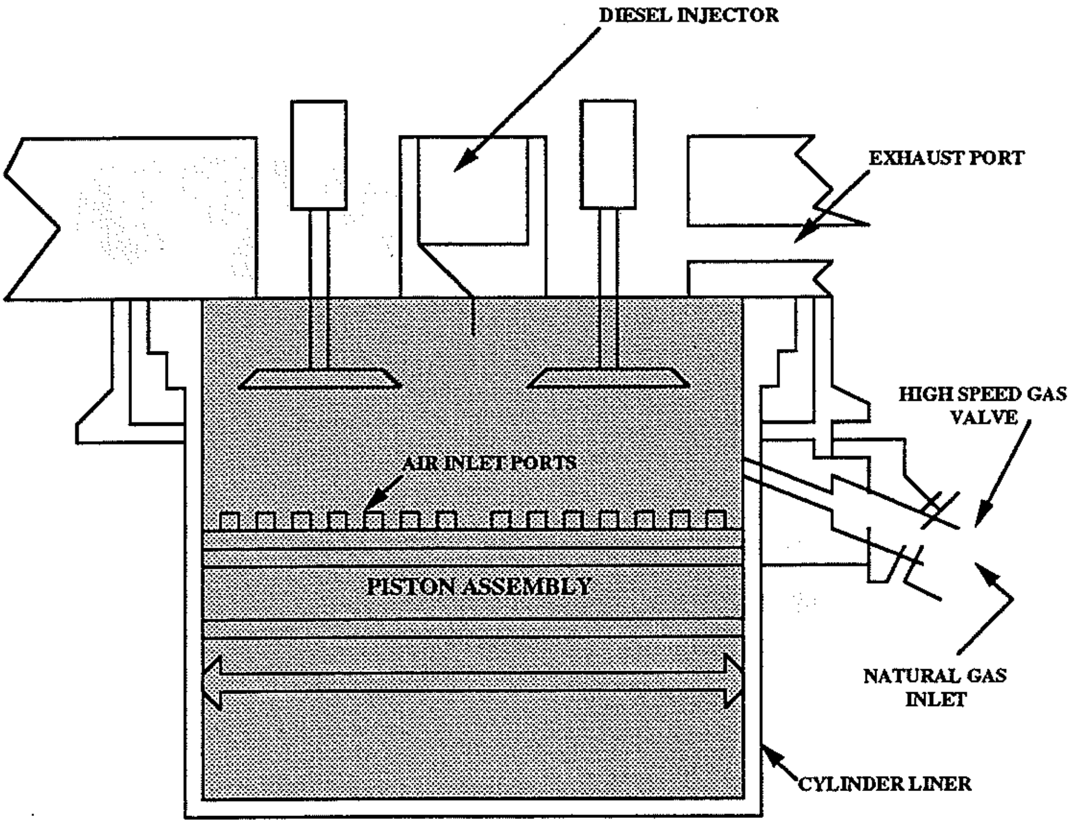
Natural gas engines can be configured to burn only natural gas, or to burn diesel or gasoline as well. Diesel or gasoline can be used to start and warm up the engine. When operating temperature is reached, the engine switches over to natural gas. Indicators on the instrument panel show which fuel is used. In the event of a malfunction, the flow of natural gas is automatically shut off and the engine switched to diesel or gasoline. Wilkins (1994:9) indicates that mixtures of natural gas and diesel can be burned, although much higher compression ratios are required than the spark-ignited natural gas alone. This was essentially a transitional arrangement as spark-ignited natural gas technology was developed.

Issues of safety and cost associated with fuel conversion and utilization surface when consideration is given to transit bus fuels technology. Advocates for the use of alternative fuels insist that the risks are low, pointing to the use of the fuels in millions of residences. Skeptics of the use of such fuels question the long-term safety and total costs of alternative fuels, particularly natural gas as the alternative fuel choice.

1.4 The Problem Addressed

Successful implementation of the Clean Air Act will require a clear understanding of issues that impact decisions made about using these fuels. In a transportation brief issued by the Governor's Energy Office of Texas (March-April, 1993), it is noted that "there are no easy or obvious choices

Exhibit I
Pilot Ignition Natural Gas Piping (Series 92, 6V-92 TA DDEC)

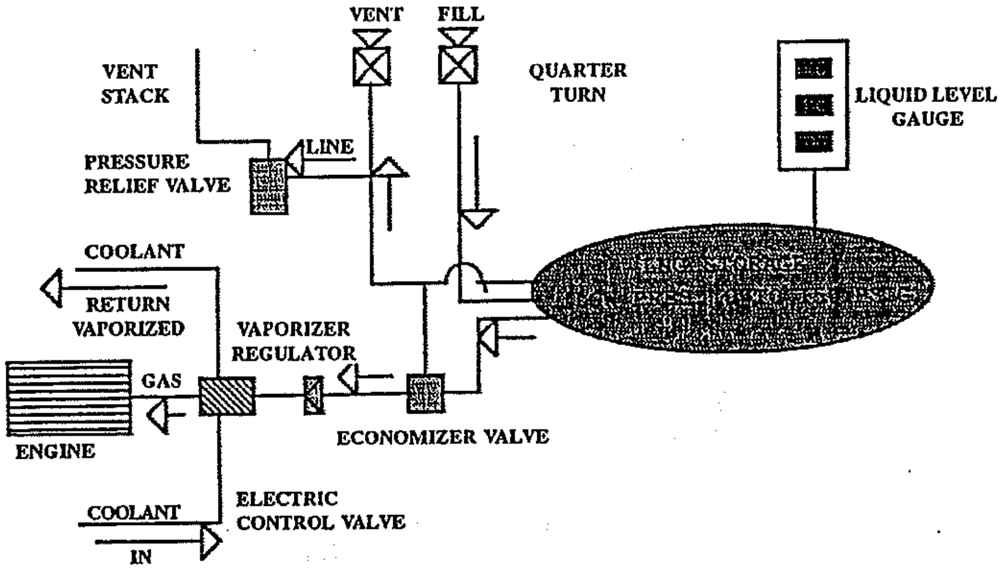


DIESEL INJECTOR:
Point at which diesel in injected.
NATURAL GAS INLET:
Point at which Natural Gas is injected.
HIGHSPEED VALVE:
Controls the flow of Natural Gas to the engine.
EXHAUST PORT:
It is the outlet for the exhaust.

EXHIBIT 1

Source: Houston METRO

Exhibit II
On-Board LNG Fuel Delivery System (Spark Ignited Engine)



LNG STORAGE: LNG is stored in the tank at a pressure of 0 - 150 PSIG.

LIQUID LEVEL GAUGE: Shows the amount of LNG in the tank.

ECONOMIZER VALVE: Controls the flow of LNG to the engine.

ELECTRIC CONTROL VALVE: Helps to vaporize the fuel.

VAPORIZER REGULATOR: Regulates the flow of vapors to the engine.

COOLANT: Keeps the engine as well as the vaporizer regulator cool.

FILL: LNG is filled through this point which in turn goes to the storage tank.

VENT: Exhaust for vapors.

Source: Houston METRO

for alternative fuels and, in fact, there are conflicting findings regarding the pros and cons of these fuels."

When considering the utilization of alternative fuels, several basic questions appear to be relevant. These include: What is it? How does it compare with gasoline or diesel? Is it easy to use? How does it work in existing vehicles? What does it cost? What kind of service support exists? What are the aggregate benefits and costs?

Additional concerns relate to how these alternative fuels are obtained or delivered, safety, storage, transitional problems, maintenance and overall performance. In order to illuminate the costs and benefits of an alternative fuel, and to explore issues related to the previous questions, this research utilized a case study approach in the assessment of a selected alternative fuel.

The rationale for this approach lies in the need for an understanding of policy issues pertaining to alternative fuel research, development, and implementation. Much of the research on alternative fuels addresses major national issues such as relative cost, environmental benefits, fuel supply and the distribution system, impacts on foreign oil energy security, and consumer acceptance. (Governor's Energy Office, January 1991: 1). *The Clean Fuels Report,* published by J. E. Senior Consultants, is one exception. It provides a comprehensive coverage of transportation fuels initiatives by the public and private sector. To expand the body of knowledge pertaining to alternative fuels development, this study documents and summarizes relevant findings. The development of an adequate refueling and servicing network may also be aided by documenting the experiences of alternative fuel conversion initiatives.

Using a combined approach that includes a general survey of transit industry experiences in alternative fuels development and a case study of a project in progress, an attempt is made to document, in a systematic way, the experiences of one public transit agency's efforts to develop and implement a comprehensive alternative fuels program. To produce a measurable decrease of harmful exhaust emissions for its fleet of vehicles, a Houston-based project by Houston METRO examined the feasibility of LNG and other alternative fuels for potential use as a substitute for diesel fuel. An explanation of the various fuels with the potential for serving as an alternative for diesel fuel is found in the next section.

1.5 Overview of Alternative Fuels

Several fuels have been named as alternative fuels for transportation purposes. They include: Natural gas, methanol, ethanol, electric vehicles, hydrogen, LPG/propane, and reformulated gasoline. All are in production at the current time. Only liquefied natural gas (LNG) is assessed in the case study found in this report. LNG is compared with other fuels, where appropriate.

NATURAL GAS (NG) - is widely used in Texas as a heating fuel and to generate electricity. Like gasoline or diesel, NG is a hydrocarbon. It is found underground, often with petroleum deposits, and is made up of several gases, with methane (CH_4) comprising approximately 85 to 95% of NG commonly used.

METHANOL AND ETHANOL - Methanol is a liquid commonly called wood alcohol that is usually produced from natural gas. Ethanol or grain alcohol is usually produced by fermentation of agriculture products, such as corn or sugar cane. Methanol is poisonous if ingested in small quantities while ethanol can be consumed in the form of alcoholic beverages. Both alcohols have higher octane ratings than gasoline, making them attractive for spark ignition engines.

LIQUEFIED PETROLEUM GASES (LPG) OR PROPANE - LPG, sometimes called propane, is a mixture of many gases, but primarily propane (C_3H_8) and butane (C_4H_{10}). It is the heavier parts of the natural gas and the lighter parts of petroleum. LPG for automobile use is typically 95% propane, called HD-5. LPG has been used as a vehicle fuel for many years, with an estimated 18,000 LPG vehicles in Texas and 300,000 in the United States. LPG can be burned in conventional, spark-ignition engines with modification.

HYDROGEN - i s a gas rarely found by itself in nature. It often occurs in combination with other elements. It is the fuel which powers the space vehicles in the United States and is attractive because of its high energy conversion efficiency, low emission characteristics, and the fact that it can wheel drive, pioneered the catalytic converter, designed and installed sophisticated engine-control electronics and completely "reformulated its products."

A profile of selected studies pertaining to the state-of-the-art of alternative fuels development is included to serve as a background for a discussion on fuel costs and related impacts which will follow later in this report.

1.6 State-of-the-Art: Energy and Alternative Fuels

This section provides a general description of previous studies involving alternative fuels development and their findings. It is followed by a discussion of the findings of a survey of public transit systems in relation to alternative fuels development and utilization.

The Congressional Office of Technology Assessment (OTA) released a report describing energy strategies for the United States over the next 25 years in August, 1991. The report presents an overview of choices open to energy policy makers and the role that technology can play. According to the report, "Energy Technology Choices: Shaping Our Future," the three greatest challenges facing energy policy makers are easing emissions of carbon dioxide, assuring a long-term supply of reasonably priced, convenient fuels, and protecting the country against disruptions of petroleum imports.

The report lists several alternative fuels that are of primary interest for light-duty fleets in the United States. These include: Reformulated gasoline, alcohol fuels — methanol and ethanol, compressed or liquefied natural gas, hydrogen and electricity. Each of the aforementioned fuels has advantages as well as disadvantages. "Aside from fuel cost, the major barrier that most alternative fuels must overcome is the need to compete with the highly developed technology and massive infrastructure that exists to support the production, distribution, and use of gasoline as the primary fleet fuel," says the report (*The Clean Fuels Report,* September, 1991:3). Figure 2.1 presents some of the tradeoffs among the alternative fuels relative to gasoline. The findings indicate that each of the suggested alternative fuels has one or more features, e.g., high-octane, low emissions potential, that imply some important advantage over gasoline in powering vehicles.

In a recent study, Booz-Allen & Hamilton, Incorporated assesses the use of alternative fuels by public transit authorities with a focus on small transit operations. As a result of an economic impact analysis, the study concludes that the switch to alternative fuels will require a substantial increase in both operating and capital costs. Cost impacts were quantified for the major cost elements affected by a switch to alternative fuels. Table 1 contains data on total incremental increase in annualized cost over baseline diesel operations for each of the alternative fuels and for selected fleet sizes.

The data indicate that for a fleet of 10 transit buses, the alternative fuel that would result in the least increase in annualized cost is liquefied natural gas, while the most expensive alternative fuel, on an annualized cost basis, would be liquefied petroleum gas. The 50-bus fleet would also realize the least increase in annualized cost if the switch were made to liquefied natural gas, although

Figure 2.1
Pros and Cons of Alternative Fuels

Fuel	Advantages	Disadvantages
Methanol	- Familiar liquid fuel - Vehicle development relatively advanced - Organic emissions (ozone precursors) will have lower reactivity than gasoline emissions - Lower emissions of toxic pollutants, except formaldehyde - Engine efficiency should be greater - Abundant natural gas feedstock - Less flammable than gasoline - Can be made from coal or wood (as can gasoline), though at a higher cost - Flexfuel "transition" vehicle available	- Range as much as one-half less, or larger fuel tanks - Would likely be imported from overseas - Formaldehyde emissions a potential problem, especially at higher mileage, requires improved controls - More toxic than gasoline - M100 has nonvisible flame, explosive in enclosed tanks - Costs likely somewhat higher than gasoline especially during transition period - Cold starts a problem for M100 - Greenhouse problem if made from coal
Ethanol	- Familiar liquid fuel - Organic emissions will have lower reactivity than gasoline emissions (but higher than methanol) - Lower emissions of toxic pollutants - Engine efficiency should be greater - Produced from domestic sources - Flexfuel "transition" vehicle available - Lower carbon monoxide with gasohol (10 percent ethanol blend) - Enzyme-based production from wood being developed	- Much higher cost than gasoline - Food/fuel competition at high production levels - Supply is limited, especially if made from corn. - Range as much as one-third less, or larger fuel tanks - Cold start is a problem for E100
Natural Gas	- Though imported, likely North American source for moderate supply (1 MMBPD of gasoline displaced) - Excellent emissions characteristics except for potential of somewhat higher nitrogen oxide emissions - Gas is abundant worldwide - Modest greenhouse advantage - Can be made from coal	- Dedicated vehicles have remaining development needs - Retail fuel distribution system must be built - Range quite limited, need large fuel tanks with added costs, reduced space (liquefied natural gas (LNG) range not as limited comparable to methanol; LNG disadvantages include fuel handling problems and related safety issues) - Dual fuel "transition" vehicle has moderate performance, space penalties - Slower refueling - Greenhouse problem if made from coal
Electric	- Fuel is domestically produced and widely available - Minimal vehicular emissions - Fuel capacity available (for nighttime recharging) - Big greenhouse advantage if powered by nuclear or solar - Wide variety of feedstocks in regular commercial use	- Range, power very limited - Much battery development required - Slow refueling - Batteries are heavy, bulky, have replacement costs - Vehicle space conditioning difficult - Potential battery disposal problem - Emissions for power generation can be significant

Source: The Clean Fuels Report, September, 1991 Pg. 3

compressed natural gas is also an attractive scenario. In this case, the highest cost alternative would switch to methanol. When a comparison of selected alternative fuels was made, it was revealed that methanol was the most expensive fuel in the 200-bus fleet scenario, while compressed natural gas and liquefied natural gas were the least expensive. Again, Table 1 indicates that liquefied petroleum gas is also a competitive alternative to this fleet size.

Table 1
TOTAL INCREMENTAL INCREASE IN ANNUALIZED COST OVER BASELINE DIESEL OPERATIONS
(Dollars per Year)

	LPG	CNG	LNG	Methanol	DieselW/Trap
10 Bus Fleet					
Increased Fleet Fuel Costs	20,571	(3,642)	7,308	43,371	0
Fuel Facility Operating Costs	1,650	16,100	4,400	1,650	0
Increased Fleet Maintenance Costs	30,000	30,000	30,000	30,000	15,000
Replacement Costs	25,000	41,667	33,333	16,667	16,667
Annualized Fuel Facility Capital	11,800	64,139	30,376	7,687	0
Annualized Maintenance Facility Capital	8,762	14,604	14,604	8,762	0
Total	97,783	84,125	75,042	91,688	31,667
50 Bus Fleet					
Increased Fleet Fuel Costs	137,143	(24,278)	48,722	289,143	0
Fuel Facility Operating Costs	1,900	49,300	156,000	1,900	0
Increased Fleet Maintenance Costs	200,000	200,000	200,000	200,000	100,000
Increased Fleet Replacement Costs	125,000	208,333	166,667	83,333	83,333
Annualized Fuel Facility Capital	18,810	75,355	83,533	14,907.	0
Annualized Maintenance Facility Capital	17,524	26,287	26,287	17,524	0
Total	500,377	433,355	430,988	574,376	183,333
200 Bus Fleet					
Increased Fleet Fuel Costs	548,571	(97,114)	194,887	1,156,571	0
Fuel Facility Operating Costs	2,400	182,500	37,800	2,400	0
Increased Fleet Maintenance Costs	800,000	800,000	800,000	800,000	400,000
Increased Fleet Replacement Costs	500,000	833,333	666,667	333,333	333,333
Annualized Fuel Facility Capital	71,266	165,956	192,418	44,676	0
Annualized Maintenance Facility Capital	35,049	46,732	46,732	35,049	0
Total	1,957,286	1,931,408	1,938,504	2,372,029	733,333

Source: The Clean Fuels Report, September, 1991

The Booz-Allen study advises that there are regional biases regarding the benefits of each of the alternative fuels. These biases should be taken into consideration when reviewing the findings of previous studies.

A survey of selected transit properties was conducted in 1991 for the purpose of determining those actively involved in demonstrating alternative fuel buses. A questionnaire was distributed to 50 large-sized public transit systems in the United States. Thirty-two (32) responses to the questionnaire were received. The findings of the survey are discussed in the "Summary of Findings" section.

II. PROJECT DESCRIPTION AND INSTITUTIONAL FRAMEWORK

Increased fuel efficiency for automobiles, buses, and other vehicles and the use of alternative, non petroleum fuels are major means for reducing the transportation sector's vulnerability to fuel supply interruptions and price shocks. Alternative fuels are also expected to help address air quality and other environmental problems generated by tailpipe emissions. Policies in Texas and other parts of the nation are already in place to promote the widespread use of alternative transportation fuels.

The Alternative Motor Fuels Act of 1988 (AMFA) promotes the development and use of methanol, ethanol, and natural gas as alternative fuels. The Act also provides incentives for automobile manufacturers to produce alternative-fuel vehicles, and it authorizes studies of electric and solar-powered vehicles.

In 1992, there were four Alternative Motor Fuels Act (AMFA) Federal demonstration projects, consisting of 81 vehicles, and located in the District of Columbia, Detroit, Michigan, and Los Angeles and San Diego in California. Of these 81 vehicles, 16 were conventional gasoline vehicles (control vehicles) and 65 were alternative-fuel vehicles which operated on any mixture of gasoline and methanol, up to a mixture of 85 percent methanol.

As part of the effort to promote alternative-fuel vehicles, the Metropolitan Transit Authority of Harris County began an aggressive alternative fuels project in 1990. The project was designed to test the feasibility of using liquefied natural gas (LNG) as an alternative to diesel fuel in transit buses. The project entailed promoting the use of alternative-fuel vehicles, including a conversion of a substantial portion of the existing fleet of vehicles that already existed in the inventory of Houston Metro.

This section of the report contains results of the case study of the results of Houston METRO's experiences in converting diesel-operated buses to LNG-fueled buses. It provides data on costs associated with the alternative fuels conversion project, actions taken to deal with problems inherent in the use of LNG, and future research needs of the transportation industry relative to the continued use of alternative fuels technology.

The Agency had more than 1,160 buses as of May, 1992 in its fleet which operate on approximately 2,100 miles of bus routes, providing over 60 million passenger trips annually, according to a report on "Liquefied Natural Gas Vehicle Experience.." (May, 1992). The report also notes that "Metro utilizes approximately ten million gallons of diesel and 380,000 gallons of gasoline per year. Fuel costs were estimated to be about 4.5% of operating costs; equivalent to approximately 18 cents per mile. It should be pointed out that the aforementioned figures reflect data as of May, 1992.

By October, 1993, Houston Metro had increased its bus fleet to 1,500 vehicles. The Agency operates two fleets, which includes 1,200 transit passenger buses, and some 300 support vehicles. Both of these fleets are expected to increase during the next decade to about 1,600 buses and over 400 support vehicles. The annual miles operated each year by both fleets exceed 46 million, according to a report by George A. Herman, Deputy General Manager of Maintenance for the Metropolitan Transit Authority.

2.0 Objectives and Approaches

The primary objective of the study was to conduct a case study of a large-scale fuel-conversion demonstration project to assess selected costs and related issues. Several approaches were used to document the successful demonstration project and its results. An inventory of public transit agencies engaged in demonstration projects involving alternative fuels was conducted with a representative sample of public transit systems in the nation. Included in the survey were questions pertaining to fuel supply arrangements, fuel reserve storage requirements and/or deficiencies; and future plans for managing energy resources and fuel conversion /alternative fuels projects planned or in operation.

The case study approach was used to document methodological and logistical problems encountered during the course of projects using an alternative fuel and a control (diesel) fuel. To derive information suitable for use in the analytical process, monthly reports developed and distributed to the Board of Directors of The Metropolitan Transit Authority of Harris County (METRO) were used. To further provide insights into the results of the demonstration project on the alternative fuel, the evaluative methodology used by METRO was used to identify important variables for use in developing a conceptual framework or model. The technical service bulletins issued during the Liquefied Natural Gas (LNG) project were one of the main sources used in documenting the findings of the study.

The monthly status reports on the alternative fuel demonstration project covered activities or project variables, including data on accumulated mileage, road calls/unscheduled maintenance, fuel consumption, fuel cost per mile, alternate fuel purchases, schedule of activities for the next period, personnel, safety, and diesel emission test results.

Major cost components were considered in the study. Fuel cost for LNG trucked to the refueling site. For this fuel supply scenario, cost comprised three major elements: LNG plant gate cost, trucking cost, and fuel facility capital cost. Another cost involved total costs for transit buses. Four major components were considered: Vehicle cost, maintenance cost, maintenance facility modification cost and fuel cost. A "best-case" analysis was performed to assess costs for converting transit buses from diesel to liquefied natural gas (LNG) fuel.

It should be noted that the "time factor" also impacted the results of the study. Since the project is still in progress, the findings of the study should be viewed within the framework of an on-going evaluation activity. This research represents the first phase of the evaluative process. Data for the study are based on a "best-case" scenario for a specific period. The findings illustrate a progressive move toward the utilization of alternative fuels by the public and private sector. The urgency with which the agencies must deal with implementing mandates imposed by the Clean Air legislation makes the results of early phases of the project central to policy- and decision-making.

2.1 Experimental Design

The alternative fuels demonstration project was initiated during 1990. An in-depth analysis of technically feasible alternative fuels was conducted. The first phase of the demonstration project was exploratory in nature. The Metropolitan Transit Authority of Harris County conducted a state-of-the-art review of the operational characteristics of its diesel buses. Bus range, payload, service demands, maintenance requirements, and duty cycle all heavily influenced the staffing of the organization. It was also recognized that any alternative fuel which resulted in more buses being required to provide the existing level of public service, or which would "demotivate" the ridership because of an increase in fares would ultimately defeat the clean air objective. Either scenario would discourage ridership and place more vehicles and emissions on the streets of Houston — a high non-attainment area.

2.2 The Alternatives

Houston METRO developed a series of transit-practical criteria to guide the selection of an alternative to diesel fuel. The alternative fuel criteria included the following: Safety, similar range, similar weight, fast fill fueling, retrofit-ability, performance, dependability, similar maintainability, reduced emissions, similar economics, and domestic availability and others.

Four alternative fuels were investigated. These included methanol, propane, and both compressed and liquefied natural gas. According to the findings of the investigation, methanol and propane proved to have disadvantages which weighed heavily against their selection, including safety, cost, availability, spill hazards, and mechanical efficiency and high maintenance implications with methanol; price/domestic supply fluctuations in the instance of propane. Methanol's aldehyde emissions were also a concern. Natural gas offered significant advantages, not the least of which included an assured 60-year supply of conventionally recoverable domestic reserves; 28 percent of which can be found in the State of Texas. The low cost, low particulate emissions, and record of demonstrated success in gasoline engine conversions — all were key factors that influenced the decision to use liquefied natural gas (LNG) in the experimental fuel conversion project.

Two forms of natural gas were examined: compressed and liquefied natural gas. The findings revealed that the prospect of utilizing compressed natural gas in a large, heavily worked fleet posed some problems and major challenges. The unavoidable fast-fill requirement (four to six minutes for 120 diesel gallon-equivalents) required significant and costly compression capability. Bulk storage was not an option since such storage was in the pipeline. The weight, volume, and range penalties were proven to be unacceptable for METRO's fleet, according to reports by Russell Pentz and James P. Lewis (1992). It was felt that the CNG tankage required to provide a 350-mile range would severely reduce the peak hour standing load opportunity utilized by all transit systems. It would also require significant structural and component changes on the bus. These changes also negated any opportunity for a simple retrofit on existing buses, an important economic consideration of the project.

Cryogenics, i.e., the liquefaction of natural gas by cooling it to -260 degrees Fahrenheit, could solve many of the problems by condensing SCF of natural gas into one cubic foot of liquid volume. At this temperature, in the comparison of CNG and LNG, the gas remains liquid at ambient pressure and will immediately attend to fast-fill demands. The low pressure requirements (40 PSI) to fuel vehicles are easily and economically met while foregoing the extremely heavy compression tanks associated with CNG. This revives the prospect of retrofitting an existing diesel bus without major structural/component modifications, and does not require sacrifice of the standing passenger load.

After considerable research and development of alternative fuels, Liquefied Natural Gas (LNG) was selected as METRO's choice in response to a law passed by the Texas Legislature. In short, the law basically said "that no vehicle may be purchased or leased by a municipal authority after September 1, 1991, that cannot utilize natural gas as the fuel source." (Herman, 1993: 1). In response to this requirement, Houston METRO began the transition from diesel to Liquefied Natural Gas (LNG) for both revenue and non-revenue fleets. The decision to use LNG was based on the belief that it met METRO's operational and safety needs.

The selection of LNG as an alternative fuel made it necessary to make substantial changes in the agency's procedures. It also required disciplinary and attitudinal changes among maintenance personnel because of the need for these individuals to become familiar with certain requirements unique to the conversion project. To expedite the changes, the Agency encouraged personnel to pursue training classes to improve their skills. Alternative fuel technicians were assigned to specific facilities used in the LNG conversion project to assist, train, and answer questions on a none-to-one basis. A prime concern was the safety of the conversion project in general and of the employees in particular. To protect the integrity of the conversion project and to ensure the safety of the alternative fuels technicians and other workers, specialized service bulletins were issued to enhance procedures and requirements.

Like diesel, the transport and on-site bulk storage of liquefied natural gas (LNG) is a proven process which assures continuity of fuel supply. The liquefaction process also enhances fuel quality by stripping out many impurities (water in particular) that are commonly associated with pipeline gas. LNG also was perceived to afford the opportunity for cogeneration; "utilizing the supercold fluid to cool various mechanical components enroute to the engine, where it arrives and is utilized in its gaseous form." Space-age vacuum insulation of the light-weight fuel tanks offer weeks of "holding" time on vehicles and months in bulk storage containers.

The results of the investigation to determine the best alternative fuel to use in the conversion project may *not be universally applicable. The results of the study indicated that "it is fairly obvious that an automobile which uses the equivalent of ten gallons of fuel per week is not a candidate for LNG, nor is a bus fleet that does not require standing loads or 18-hour range capabilities. Weight and dimensional comparisons for Neoplan METRO buses are found in Figure 3.*

Figure 3.
Neoplan Carbon Fiber METROLINER

Length	35'4"
Width	8' 4"
Height	8' 11"
Height (Interior)	7' 10"
Floor Height	1' 1"
Weight	14,329 LB. (W/O Air Condition)
Gross Vehicle Weight Rating	27,329 LB.
Capacity	33 Seated Plus 40 Standing
Fuel Economy (Empty)	10.9 MPG

Alternative Fueled Buses at Houston METRO

Source: Photographs supplied by Houston METRO, 1995.

The emissions testing results also figured prominently in Houston METRO's decision to use LNG as opposed to CNG. Data from the investigation reveal that from the engine's standpoint, there is little if any difference between natural gas which comes from a high pressure cylinder or from a cryogenic LNG fuel tank. A further examination of preliminary emission testing results from engine manufacturers such as Caterpillar Model 3306G and Detroit Diesel Model 6V92 Pilot Ignition Natural Gas engines indicate that the emissions are well below the 1993 standards. Methane catalyst were used in each instance.

2.3 Current Issues and Technical Developments

Some current issues and technical aspects of the feasibility tests to determine alternative fuels use were also examined. These included issues of safety, on-board fuel measurement, fuel system holding time, loss of power, weathering, fill connections, fast fill, retrofit, fuel quality, dedicated single fuel vs. dual fuel, equipment costs, and decisions regarding fuel production and supply. Policies regarding each of these issues are discussed in the sections that follow.

On Board Fuel Measurement - In the METRO alternative fuels project, each bus was refueled and serviced every night. Fuel measurement devices located in the fueling compartment to determine when the tanks were full were also tested.

Fuel System Holding Time - The holding time specified for the METRO bus fuel tanks (192 hours) appeared adequate for all of its operations. Special procedures were used when maintenance or storage occurred inside. Fuel tanks were de pressurized and the tank pressures monitored.

Loss of power and Weathering - It was assumed that from theoretical considerations, the lower density of natural gas should result in lower power output for the same engine displacement. It was also assumed that the power loss was recoverable through engine modifications. In fact it was felt that the power of the diesel engine equivalent may be exceeded through cogenerative effects on the air-to-air charge systems. LNG liquid changes composition (weathers) if bulk storage evaporation is permitted. This results in an increase of the heavier natural gas components (ethane and propane) which, in turn, causes unacceptable engine performance in high-compression engines. METRO contracted for LNG with a methane content of not less than 94%, with the intent of ultimately recovering evaporative "boil-off" in its fueling stations.

Fill Connections and Fast Fill - Initially none of the fuel connection nozzles available were found to be completely acceptable. METRO encouraged two manufacturers to develop improved equipment prototypes. Through a cooperative effort with the manufacturers, the technical problems were resolved. Specific features were added which included dry break, quarter-turn lock and an interlock so that flow could not occur unless the coupling was in place. This action was a solution to METRO's immediate problem. Modifications notwithstanding, there is need for the industry to consider standardization of a safe, reliable and economic refueling coupling.

Another concern of the feasibility assessment of alternative fuels related to time for servicing. The current time needed to service a bus at Houston METRO including refueling, was six minutes, as of May, 1992. The demonstration project's goal was to service and refuel LNG-fueled buses in the same time required for diesel buses.

Retrofitting, fuel quality, equipment costs, and other issues were also examined. In a review of the test results on the effects of fuel composition on engines, it was noted that most of the testing had emphasized emissions rather than engine performance. A cooperative effort was made to determine the optimum LNG quality required for engine performance and emissions.

A major consideration was given to issues regarding dedicated single fuel versus dual fuel. Operational experiences on monofuel engines began in 1992. Other issues of concern in the alternative fuels project included equipment costs. Data on costs were collected from previous studies and incorporated by Houston METRO into the decision making process. Acurex Corporation conducted a study for the Gas Research Institute (GIs). The objective of the study was to evaluate the potential of LNG as a vehicle fuel, to determine market niches, and to identify needed technology improvements. Interim findings relative to LNG vehicle technology, economics, and safety were presented. In addition to emphasizing the importance of assessing whether heavier hydrocarbons should be allowed in LNG vehicle fuel, the report also stated that "lowering the cost of small-scale liquefiers would significantly improve the economics of LNG vehicles.

To assess the economics of LNG fuel use, two fleets were used in the demonstration: a transit bus fleet and a medium-duty bus fleet. The transit bus fleet consisted of 200 vehicles with a baseline fuel economy of 3.9 miles per gallon. The medium-duty truck fleet consisted of 75 vehicles with a baseline fuel economy of 6.0 miles per gallon. Table 2 summarizes total fuel costs for on-site liquefaction for both fleets, using feedstock cost of $2.50 per thousand cubic feet.

As noted in Table 2, on-site liquefaction is not economic for the medium-duty delivery truck fleet, with a fuel cost of $1.03 per gallon, equivalent to $1.56 per gallon of gasoline on an energy basis. This is due to the poor economy of scale for the small liquefied size, as well as the high labor cost to maintain the liquefied. The transit fleet achieved greater economies of scale due to the large fuel demand, reducing its costs to just under $0.54 per gallon, or $0.89 per equivalent gallon of diesel fuel. (*Clean Fuels Report,* April, 1992: 142).

Table 2
Total Fuel Costs for On-site Liquefaction Cases

Cost Element	Transit Bus Fleet	Medium-Duty Delivery Truck Fleet
Liquefier Capital Cost	$4,000,000	$1,100,000
Annualized Cost	470,000	129,000
Storage Tanks	480,000	110,000
Annualized Cost	56,000	13,000
Liquefier Operating Cost	420,000	181,000
Fueling Facility Capital Cost	1,090,000	385,000
Annualized Cost	128,000	45,000
Annual Gas Cost	935,000	118,000
Total Annualized Cost	$2,009,000	$486,000
Annual Gallons Used	3,740,000	473,000
Cost per Gallon	$0.537	$1.03

Figure 4 shows the breakdown of fuel costs for all cases. Costs are higher for the imported LNG cases, but high liquefier capital costs more than offset this difference. It should also be noted that the results of the best case analyses performed for both fuel supply scenarios to assess the effects of the favorable assumptions for LNG costs.

The study by the Acruex Corporation included four major cost components: Vehicle cost, maintenance cost, maintenance facility modification cost and fuel cost. For the analysis, it was assumed that LNG bus conversions cost of $40,000 each. It was assumed that, on balance, maintenance costs for LNG transit buses are the same as diesel buses.

Figure 4.
LNG Fuel Costs (At Dispenser) for Selected Cases

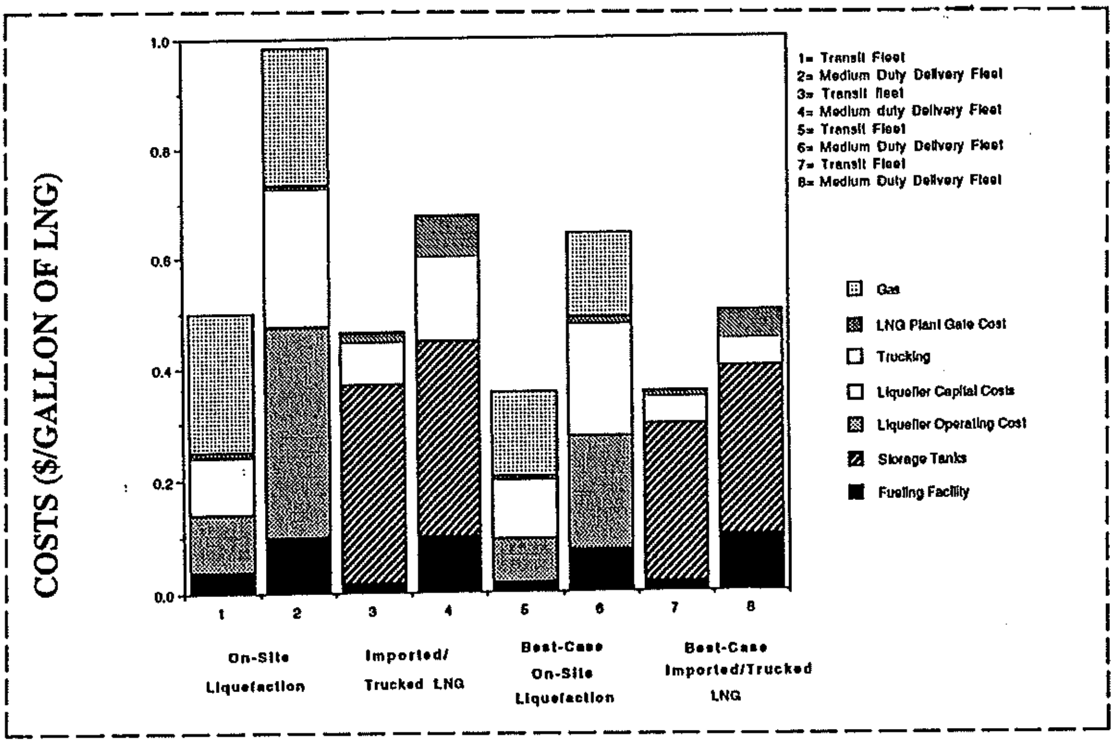
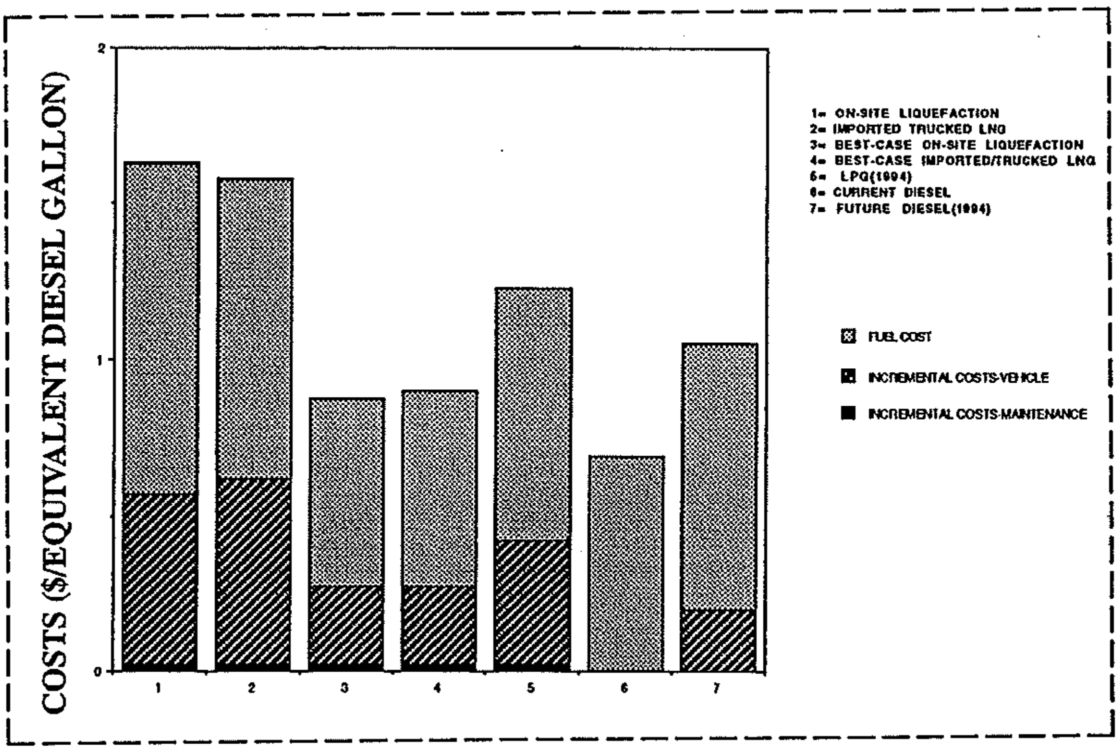


Figure 4-A.
Fuel Specific Costs For Selected Transit Fleet Cases



Based on the experiences with natural gas and other alternative fuels, according to the Acurex Corporation's report, it was estimated that $500,000 would be required to modify the maintenance facility. The cost could be potentially much higher. Fuel specific costs are shown in Figure 4-A. Acurex (*Clean Fuels Report,* April, 1992: 146) found that costs of on-vehicle equipment and vehicle conversion are major elements in bottom-line costs for LNG. The bottom-line costs results depend strongly on what is assumed for such costs and how future costs are expected to be reduced through design improvements and through economies of scale of large production quantities and how "learning curve" manufacturing experience will reduce future costs.

Taylor, Euritt and Mahmassani (1992) examined a cost-benefit model for evaluating the implications of fleet conversion and operation on compressed natural gas (CNG). A hypothetical fleet with characteristics favorable to cost-effective conversion and operation on CNG was analyzed, as an illustration of the type of fleets that may be cost-effective. The costs were classified according to capital infrastructure costs, capital vehicle costs, and operating costs. Sample fleets similar to those of the Texas Department of Transportation (TxDOT) were analyzed to identify critical benefit/cost elements in the model.

The authors conducted a final sensitivity analysis for conversion costs. Table 3 provides vehicle cost data and a summary of system costs and savings, respectively. With the base assumption of the model, a natural gas price of no more than $1.79 per thousand cubic feet is required for the conversion and operation of the fleet to be cost effective (i.e., for the 30-year net present value of savings minus costs to be positive). See: *Clean Fuels Report,* April, 1992: 138-139.

2.4 Project Description

Using previous and existing findings on liquefied natural gas as an alternative fuel and sensitivity analyses of fuel conversion cost data, Houston METRO developed policies and procedures for the implementation of its alternative fuels project. Efforts were made to assess the efficacy of several alternative fuels, including liquefied natural gas. After assessing the performance and determining the feasibility of liquefied natural gas (LNG) on test buses and automobiles, Houston METRO committed to LNG in 1990.

Table 3
Summary of Costs and Savings
(Based on 30-Year Net Present Value)

	30-Year NPV
Savings	
Gasoline Price Difference	$1,529,982
Automobiles	73,769
Light Trucks	1,201,376
Heavy-Duty trucks	254,837
Diesel Price Difference	0
Maintenance	0
Total Savings	**1,529,982**
Costs	
Infrastructure	
Land	0
Station Setup	(85,153)
Compressor	(65,902)
Storage Vessels	(240,395)
Dispenser	(24,857)
Dryer	(9,943)
Subtotal	**(426,250)**
Vehicle	
Conversion Kit	(60,629)
Tanks	(132,500)
Labor	(175,872)
OEM	(82,748)
Subtotal	**(451,748)**
Operating	(102,971)
Station Maintenance	(25,228)
Cylinder Recerttificaton	(25,228)
Power	(127,855)
Labor-Fuel Time Loss	(229,502)
NG Fuel Tax	(165,160)
Additional Training	0
Subtotal	(650,716)
Total Costs	**($1,528,714)**
Savings-Cost	**$1,268**

Source: The Clean Fuels Report, April, 1992, pg 141

Several factors affected METRO's choice of liquefied natural gas as the alternative fuel. These were:

- Energy supply
- Regulations
- Technical maturity and vehicle performance
- Relative economics
- Costs and benefits
- Related factors

After analyzing the technically feasible alternative fuels, METRO concluded that liquefied natural gas (LNG) offered optimal technical and economic advantages over other feasible alternatives (*The Clean Fuels Report, April, 1991).* Upon approval by the Agency's Board of Directors, a broad-based fuel conversion project was initiated. The Agency developed an alternative fuels schedule which was implemented. It included the largest alternatively fueled transit fleet in the United States. The LNG projects were designed to include both new and retrofitted medium and heavy-duty transit buses as well as a refueling infrastructure. The retrofit/prototype portion of the project was for demonstration purposes only.

From the outset, stringent controls and evaluation techniques were employed to determine the operational efficiency of the LNG buses, the emissions produced, maintenance requirements, special tools and special training required, safety considerations and cost efficiencies in engine production.

The ambitious alternative fuels schedule which began in 1990 involved the acquisition and utilization of an estimated 500 buses to be in placed by the end of 1994, according to a recent account in ***The Clean Fuels Report (September, 1992:125).*** From the outset, Houston METRO ordered twenty new 40-ft buses. The order specified that some of the buses be equipped with dual fuel operations on LNG and diesel. Ten of the buses would be equipped with diesel engines, with 50 percent of this fleet with particulate traps and the remaining being turbocharged. Turbocharged diesel engines served as the baseline for comparison purposes.

METRO also had a prototype LNG bus developed. It retrofitted full-size buses to operate on LNG. To further enhance the project on alternative fuels, there was need to construct permanent LNG processing, storage and dispensing units to accommodate LNG requirements.

III. SUMMARY OF RESULTS

The results of the project are summarized in the next several sections. The preliminary data in these sections draw heavily on the monthly status reports on alternative fuels of the Metropolitan Transit Authority of Houston and Harris County for the period, 1991-1992. Selected data are included in the Appendices of this report.

Some key factors have been identified by previous authors as useful tools in determining fuel conversion costs ((See: Booz, Allen & Hamilton, Inc., 1991). These conversion factors include: Fuel use, fuel and fueling facility costs, maintenance facility modification capital costs, and vehicle costs. Data for this study were analyzed within the framework of the economic impact of the switch to alternative fuels. A prevailing assumption is that the shift from diesel to alternative fuel utilization will require a substantial increase in both operating and capital costs, particularly for small transit operations. What will be the impact of alternative fuels use on medium and large-size systems?

To assess impacts associated with an alternative fuels conversion project, costs were quantified for major elements affected directly by the shift from diesel to an alternative fuel. This study focuses on these major cost elements:

- Capital Cost:
  - New fueling facilities
  - Maintenance facility modification

- Operating Costs:
  - Fleet fuel costs
  - Fuel facilities operating costs
  - Fleet maintenance costs
  - Fleet replacement costs (vehicle capital costs).

In addition to the aforementioned factors, there are other costs that should be considered in an overall assessment of fuel conversion costs. Safety and personnel issues, training, parts inventory costs, and a variety of one-time costs must also be examined in any analysis of alternative fuels utilization.

Because of the fuel conversion project used as a case study in this analysis is still in progress, the study confines its inquiry to findings within a prescribed period of time, data on fuel costs, fuel consumption and maintenance from our surveys and previous research are used in this analysis.

3.1 Alternative Fuels Survey

Houston METRO was one of several transit systems used to assess activities that are taking place in reference to meeting air quality and alternative fuels requirements. The selection of this large system related more to the choice of liquefied natural gas (LNG) as an alternative fuel than location or proximity. Critical to the analysis was the opportunity to make comparisons between natural gas and at other transportation fuels. Data from the survey and the Case Study of the Demonstration Project have been incorporated into the overall analysis.

Questionnaires were distributed to large public transit systems, including The Metropolitan Transit Authority of Harris County, to elicit information on plans and activities involving alternative fuels. Of the 50 large systems included in the survey, thirty-two (32) responded to the survey. This resulted in a 61.5 percent response rate for the survey. Answers to some questions were not applicable if public transit systems were not involved in fuel conversion projects. Other different responses pertained to those systems using alternatively-fueled buses only.

The findings of the survey indicated that 61.2 percent of the public transit systems that responded to the survey used alternative fuels. More than 38 percent indicated that they were not using alternative fuels in their fleet of buses. These responses are reflected in Table 4.

Table 4.
Percentage of Transit Systems Using Alternative Fuels (N=32)

Yes	62.2%
No	38.8%
Total	**100%**

A comparison of the results of the general survey conducted for this study was made with a similar survey conducted by Hemsley (TRB, 1993) under the Transit Cooperative Research Program in 1993. A questionnaire was used to survey 28 transit agencies located in all regions of the contiguous United States. Data from the survey indicated that over 26 percent of the agencies used Methanol as an alternative fuel compared to 22 percent in this study. The findings also indicated that over four percent used LNG and Ethanol. The largest percentage of users indicated that they used Natural Gas. More than 56 percent indicated that they used Compressed Natural Gas (CNG), with more than 8 percent using LPG (Propane). Findings in the survey for this study compare favorably with those from the Hemsley study (TRB, 1993: 31). It should be noted that Houston METRO was among the 28 transit agencies included in the study sponsored by the Federal Transit Administration in cooperation with the Transit Development Corporation under the Transit Cooperative Research Program of the Transportation Research Board.

Of the total public transit systems responding to the survey for this study, 22.2 percent indicated that they used methanol; 55.5 percent used a form of natural gas — either compressed natural gas (CNG) or liquefied natural gas (LNG). Users of propane and electricity comprised over 11 percent of the systems. As indicated in Table 5, methanol, LNG and CNG appear to be the preferred alternative fuels.

Table 5
Percentage of Public Transit Systems Using Alternative Fuels

FUEL	PERCENT
Methanol	22.2
Natural Gas	55.5
Liquefied Natural Gas (LNG)	
Compressed Natural Gas (CNG)	
Propane (LPG)	11.1
Electricity	11.2
TOTAL	**100.0**

Some public transit systems use private fueling facilities for servicing and maintaining their fleet of vehicles. Among the facilities listed were: Gas Utility, Metro Dade County Aviation Department, Western States Petroleum, Brooklyn Union Gas, Equitable Gas Company, Stewart and Stevenson and other utility companies. These facilities were generally found on the transit agency's property and at other locations. Data contained in Table 6 show the distribution of responses relative to the "location of fuel dispensing facility."

Table 6
Percentage Distribution of Responses as to the Location of Fuel Dispensing Facility

LOCATION	PERCENT
On Transit Agency Property	55.5
On Fuel Supplier's Property	27.7
Retail Fuel Station Open to Public	5.5
Other	11.3
TOTAL	**100.0**

The number of vehicles found in bus fleets of the public transit systems ranged from less than nine (9) to more than two hundred (200). The data indicated that about 16.7 percent of the public transit systems included in our survey indicated that they had less than 10 vehicles; 27.7 percent had fleets ranging in size from 10-39; 22.2 percent had fleet sizes ranging from 40-49; while 33.4 percent indicated that they had 50 or more alternatively fueled vehicles operating.

Factors Influencing the Use of Alternative Fuels

Transit agencies were asked to indicate what factors influenced their decisions to use alternative fuels. Leading factors included: compliance with the Clean Air Act, perceived operating cost savings, air quality benefits, the domestic fuel supply and the opportunity to test new technologies. Some indicated that some transit agencies initially had some skepticism about the use of alternative fuels while others responded to the challenge with a great deal of optimism.

In many ways the skepticism was reinforced when transit agencies began to experience technical problems and high costs associated with the transition from diesel to the alternative fuel chosen for use. The impending mandates of the Clean Air Act requirements and optimistic visions on the part of some agencies contributed to a continued commitment by agencies to alternative fuels.

Alternative Fuels and Vehicle Use

The most frequently mentioned vehicles used for alternative fuels demonstration projects included the following:

- Flexible
- M. A. N.
- Neoplan
- Marco Polo
- Ikarus
- Renault
- RTS-06
- Dodge
- Orio V
- Carpenter GMC
- Suburban Cummins

For purposes of this analysis, respondents to the survey were asked to indicate what they perceived to be the positive characteristics of alternative fuels. The positive benefits most frequently mentioned were: Lower emissions, lower costs, good performance, no exhaust smoke, clean exhaust emissions, cheaper per gallon equivalent of CNG, fuel costs comparable to diesel fuel, and "particulate emissions are reduced."

Public transit systems that are currently involved in alternative fuels development have encountered problems during phases of implementation. The problems listed by respondents included: Engine heat, cold start problems with CNG, lack of reliability, fuel availability, cost of operation per mile, weight, range, and reliability of equipment, glow plug and control failures, and fuel filter plugging." A few systems reported that engines failed prematurely when alternative fuel was used and "lower fuel mileage resulting in lower operating range." Other complaints related to the logistics of refueling as the number of alternative fueled buses increased. Among public transit systems surveyed some reported some negative experiences with dual fuel buses. Responses revealed that there were difficulties associated with permits and inspection, particularly when CNG was used.

Respondents were asked to compare positive features of the leading alternative fuels with diesel. The results, shown in Table 7, represent composite findings for alternative fuels as a whole (methanol, CNG, LNG, LPG, Electricity, etc.) when compared with diesel fuel use. Some of the positive features of alternative fuel included "good performance," "noise," and "clean exhaust emissions." These features were perceived to be superior for alternative fuel when compared to diesel fuel use.

Table 7
A Comparison of Positive Features of Alternative Fuel and Diesel Fuel Use, 1992.

ITEM	# RESPONDING	%BETTER	%WORSE	% SAME
Good Performance	32	40	32	28
Acceleration	32	27	43	31
Cold Start	22	30	10	60
Noise	32	89	9	2
Operation	19	76	9	15
Clean Exhaust Emission	32	90	6	4

Major issues impacting alternative fuels development were also examined in the survey. Basic needs of the fuel vehicle industry included filling station facilities, venting of maintenance facilities, different kinds of training, safety, and certified tank availability. Added to these major problems was the expressed need for standards for fuel quality.

The aforementioned attitudinal findings of the survey were closely aligned with some earlier findings from studies conducted by The Metropolitan Transit Authority of Harris County prior to its decision to use Liquefied Natural Gas (LNG) as an alternative fuel. Several fuels were considered by Houston METRO prior to selecting LNG. Other transit agencies evaluating alternative fuels actively explored the use of LNG also. As of August, 1991, Los Angeles, Baltimore, Corpus Christi, Dallas, and Sacramento were taking a serious look at LNG.

Because of the long-term nature of the demonstration project, the scope of the study has been limited to a strategic period in time. To ensure some validity and reliability, the findings — as reported in this study — are restricted to the period indicated only. Given this limitation, the summary of findings must be viewed within the confines of the number of years in which the project has been in progress.

3.2 Results of Demonstration Project

A wide range of fuels, including LNG, CNG, Methanol, Ethanol, and others, has been tested in diesel engines. This section of the report reviews preliminary test results of an alternative fuels project designed to assess the feasibility of using liquefied natural gas as an alternative to diesel fuel for a fleet of public transit buses.

The results of the alternative fuels project reflect preliminary findings. Data on fuel consumption were derived from average fuel economy data compiled from state-of-the-art demonstration projects. These data are compared with average fuel economy data compiled on a monthly basis. Cost impacts were quantified for major cost elements affected by a transition from diesel to alternative fuels. The major cost elements are: ***Capital costs*** as expressed in new fueling facilities and maintenance facility modifications; and operating costs, as an expression of fleet fuel costs, fuel facilities; ***operating costs,*** fleet maintenance costs, and fleet replacement costs (vehicle capital costs).

Previous researchers recognize that there are many other cost elements that will increase as a result of switching to an alternative fuel, including training, parts inventory costs, and a variety of one-time start-up costs. It should be noted that these costs could be substantial, especially during the transition phase to alternative fuels. However, such costs are not included in this analysis because of the potential for dependence on "the unique fleet composition and operating conditions" (Booz-Allen, *Clean Fuels Report,* September, 1992: 34-37).

The study conducted by Booz-Allen (1992) further acknowledged that " the potential increase in fleet size requirements due to the switch to alternative fuels is highly dependent on the baseline vehicle design and weight, peak and average passenger loading characteristics, local weight per axle limitations and issues." Because of these intervening variations, an "average" increase in fleet size and costs impacts were not included in the analysis.

- ***Fleet Conversion***

The Metropolitan Transit Authority of Harris County (METRO) began fleet conversion to liquefied natural gas (LNG) in October 1990. For the comparative analysis, "total fuel costs" for each of the alternative fuels are based on a sum of the following: Base case input cost data, feedstock, additive, Federal tax, diesel equivalent multiplier, cost per gallon, trap degradation (4%), and low sulfur/aromatics (CAA). The total cost is reported as a cost per gallon equivalent.

- ***An Overview of LNG As an Alternative Fuel***

Liquefied Natural Gas (LNG) is being evaluated. This section of the report provides an overview of safety and maintenance practices used by an agency, training procedures, fuel storage and handling, maintenance operations considerations, facility requirements, vehicle related issues, and environmental considerations. A synthesis of alternative bus fuels technology and practices is provided in a report published by the ***Transportation Research Board (TRB)*** (1993) under its Transit Cooperative Research Program. A portion of this discussion is based on a series of reports on various practices and the characteristics of various alternative fuels in use by transit agencies. Since this study focuses on Liquefied Natural Gas (LNG) and a selected demonstration project, most of the discussion will be confined to LNG as an alternative fuel choice.

Liquefied natural gas (LNG) is produced by cooling natural gas and purifying it to a desired methane content. According to a report by TRB (1993), LNG stored under moderate pressure in insulated tanks, at or near its boiling point (-260° F [-162° C] at 1 atmosphere).

Special training is very important with LNG because of its unique characteristics. As a cryogenic liquid, it presents special problems not found with other fuels. Its cryogenic liquid state does not lend itself to odorization, and having no odor of its own, minor leaks may not be perceptible to humans. LNG spills are especially hazardous because of the risk of personnel receiving cryogenic burns, and because the energy-dense liquid quickly vaporizes and becomes available for combustion.

Storage and Handling. LNG storage and dispensing and dispensing systems are subject to requirements for minimum separation from other land uses under NFPA and Uniform Fire Code (UFC) regulations . Distances vary depending on the code cited, adjoining land use, and LNG container volume. Containment of potential LNG spills is required, with provisions to prevent LNG from entering water drains, sewers, or any closed channel.

Refueling Operations require a keen awareness on the part of the operators and protection from cryogenic hazards. LNG refueling can be streamlined to match diesel fueling turnaround times. A cool-down cycle is also necessary before vehicle fueling can begin. The object is to cool the fuel plumbing and transfer lines to LNG temperature to prevent excessive vapor from forming during bus fueling.

Maintenance Operations. The properties of LNG introduce new hazards into bus maintenance operations. There must be assurance that leaks are not present if indoor maintenance is done. Also, the vehicle system must be well below the set-pressure for venting so that the system will not need to vent while indoors. While a bus is indoors, the system pressure must be carefully monitored to ensure that indoor venting is avoided if the pressure approaches the pressure relief setting (TRB, 1993). One option to ensure safety in maintenance operations is to consider off-loading all fuel before bringing the vehicle indoors.

Maintenance personnel must be have a clear knowledge and understanding of LNG hazards, the use of methane leak detectors, and the skills to repair the leaks. These skills and knowledge are critical to safe maintenance operations.

Facility Requirements. All facility requirements are outlined in the ***National Fire Codes: A Compilation of NFPA Codes, Standards, and Recommended Practices and Guides (1993).***

In addition to fire hazards, LNG poses some different and unusual hazards relative to other fuels. It is critical to the use of this alternative fuel that there is a keen awareness of all hazards associated with the handling, storage, and use of LNG; that there is proper training, suitable equipment, and good work practices to ensure a maximum level of safety.

Environmental considerations are of equal importance. Natural gas has the potential to significantly reduce NOx emissions when compared to gasoline or diesel fuel. Natural gas produces very low levels of particulate matter when compared to diesel fuel. With respect to environmental considerations, according to the TRB Report, LNG is an attractive fuel. Hazards to the environment resulting from a spill of LNG would be very limited, as the safety containment provisions keep the fuel in a confined area until it vaporizes or dissipates.

3.3 Fuel Costs: A Comparative Analysis

Natural gas and other alternative fuels are being considered as attractive options for replacing gasoline and diesel fuels. While there have been a considerable number of assessments of natural gas vehicles, including compressed natural gas (CNG) and liquefied natural gas (LNG), there is need to evaluate emerging issues and options through a comprehensive, up-to-date, comparative analysis. DeLuchi, Johnston, and Sperling (1987) conducted a comparative assessment of methanol and natural gas vehicles in terms of resource supply, performance, emissions, fuel storage, safety, costs, and transitions. The authors examined natural gas, coal and biomass feedstocks, and the security of foreign feedstocks. Next, vehicle performance and emissions are considered followed by an analysis of vehicle refueling and storage technology. Environmental impacts of fuel production and distribution are analyzed, followed by a review of health, flammability, transport, and end-use hazards. They also performed a detailed cost analysis that combined fuel cost and vehicle cost into discounted life-cycle cost-per-mile. Attention was also devoted to the feasibility and implications of transitions to methanol and natural gas from the current vehicular fuel system. The findings of the study indicate that natural gas vehicles may offer a slight economic and environmental advantages, but that a transition to natural gas fuel would be more difficult in the United States. They further found that neither fuel "is a suitable long-term replacement for petroleum." (Deluchi, et. al., 1987).

3.4 Fleet Conversion to Liquefied Natural Gas (LNG): Major Findings

The application of Liquefied Natural Gas (LNG) as a vehicle fuel for large centralized fleets has an advantage over all other alternative fuels in three areas: Weight, range and quality of fuel. Data from the demonstration project of the Metropolitan transit Authority of Harris County (METRO) indicate that disadvantages to the use of LNG as an engine fuel include the following: the lack of a proven transit technology; corporate knowledge in several areas; LNG/cryogenics, on board fuel systems, fuel station designs, equipment for fuel transfer from stations to vehicles, engine availability and safety concerns.

The approaches used by METRO to resolve issues pertaining to the disadvantages, including emissions of the various engine designs, were as follows:

- ***Engines*** - In the past most natural gas conversions consisted of low compressions and low horsepower engines that in general used fumigated type of fuel delivery system. The application of electronics in the engine configurations (including the delivery system) made a distinct improvement over the former natural gas applications.

The primary engine utilized in Houston METRO's bus fleet is the 6V92TA Detroit Diesel pilot ignition natural gas (PING) electronically
controlled engine. This engine develops a horsepower rating of up to 300, well over most previous designs.

Precision timing through the use of electronics to inject natural gas into the combustion chamber has made the 6V92 PING a practical addition to the heavy-duty engine technology. The performance of this engine equals that of a normal diesel fueled engine, which is considered to be standard in the transit industry.

Operation of the engine, depending on the particular bus application the electronics, can be programmed for various horsepower ratings up to 300. Precision timing has an additional payoff by reducing emissions.

The engine requires 300 PSI positive pressure for the Lucas Gas Valves which perform the same function as fuel injectors. The Lucas Valves are attached just above the air-ports and directs gas electronically to the two-cycle engine. In order to achieve the 300 PSI positive pressure. a cryogenic pump and tank system were designed. Utilizing a cryogenic pump, common in the industry for years, engineers and technicians downsized the pump and pressure along with utilizing hydraulics to provide the driving force required for operation.

During the past several years, natural gas engines have become available from a number of sources, including Detroit Diesel, Cummins, Hercules, General Motors, Ford, and Mack. Similar fuel delivery systems are in the process of being developed by manufacturers.

Performance of all series of natural gas heavy duty engines have been equal to normal diesel powered equipment with changes in the rear-end ratios and converters. According to an October, 1993 report on fleet conversion by Houston METRO, "the key to success of the natural gas program is to make the vehicle transparent to the operator as far as performance in everyday service is concerned. These goals have been accomplished at Houston METRO."

Additionally, a number of unleaded gasoline powered vehicles have been converted which utilize the 460 and the 302 cubic inch Ford engines using natural gas. These vehicles also use electronic technology developed in previous years to control engine operation in lieu of the older fumigation systems common in the past.

The range of vehicles equipped with Liquefied Natural gas (LNG) equals, or surpasses that currently enjoyed by diesel and gasoline powered units without adding significant weight. The quality of LNG fuel helps to reduce emissions with results that are significantly below the low sulfur diesel fuel and reformulated gasoline.

IV. MAJOR ASSUMPTIONS AND FINDINGS

4.1 LNG Engines

The findings of the fuel conversion demonstration project at Houston METRO did much to dispel certain myths associated with liquefied natural gas. It was a common belief that during the initial conceptual planning for the LNG program at METRO, that LNG could be used because of its coldness as a co-generation catalyst for certain applications. These applications included cooling for air conditioning, transmission oils, retarders, engines and for the engine air intake systems. A realistic assessment of these applications indicate that this is not achievable. The expansion rate and temperature rise is dramatic when the LNG leaves the holding tanks on the vehicle for delivery to the engine. Therefore, the cold temperature of the liquid fuel is not available in most applications.

According to the Houston METRO report, "Burlington Northern Railway has spearheaded the use of LNG for locomotive engines. They have used the coldness of the liquid to reduce the air intake temperature on locomotives presently operating on LNG." This was accomplished by providing a path through the inter-cooler prior to the fuel going to the engine. The cold temperature of the liquid fuel is not available in most applications. The Agency has tested a RTS04 model 6V92TA DDEC PING powered bus and installed similar applications.

Another assumption evaluated during the fuel conversion phases was that reducing the temperature of the air intake increases performance, horsepower and fuel mileage. During the course of the fuel conversion process, it was found that this assumption was partially valid. Certainly reducing the air intake temperature of any engine increases air density which increases performance and fuel mileage. This application increases the efficiency of the engine itself. However, according to findings to date, testing in progress at this time indicates that too much reduction in the air intake temperature tends to increase emissions. Houston METRO continue to experiment with using LNG in co-generation for the air intake on a number of applications. One such application involves 6V92 PING engine This experiment has the potential for recapturing the BTU's lost in the fuel during the vaporization process. The LNG runs through the air intake system prior to the gas regulator. This procedure will allow the previously lost BTU's to be used to cool the air intake area.

The aforementioned assumptions which were tested by Houston METRO's fuel conversion project pertain to engine. The experimental phases of the project also considered assumptions about the fuel delivery system.

4.2 Fuel Delivery Systems

For the past several years, fuel delivery systems for LNG have been built by manufacturers for application to buses and other types of vehicles. A review of the state-of-the-art on the history of cryogenic fuel indicates that there have been several attempts to use LNG. The results of these efforts have been generally successful.

There were some problems with the delivery systems, however. One of the most notable problems encountered was leakage. The leakage appears to be associated with the very low temperature of the fluid and the dramatic expansion rate when exiting the tankage system. Another problems discovered during the application of the fuel delivery systems was that after a number of applications, the quality of the material used for installation of the fuel tanks and connecting lines was of major importance. Connections should be welded in order to reduce the number of removable fittings and to lessen the possibility of sporadic leakage.

If fittings are repaired in certain applications for the maintenance of the system, high quality fittings need to be used. Presently, METRO uses fittings that are produced by Swagelok. The experience of the agency with this product has been extremely good, according to the October, 1993 preliminary report of Houston METRO. Further, "rarely has there been any leakage once the system is installed and operating." Due to the temperature changes inherent in cryogenics, the type of threat sealant is also important. Houston METRO tested several sealants. To date, they have not found one to be completely satisfactory.

Houston METRO currently uses two types of fuel delivery systems. One is the high pressure (300 PSI) system which requires a submersible pump in the LNG tanks for delivery of the fuel. The second type of system is different and uniquely designed for the lower compression engines that require less pressure. Gas pressure is of extreme importance, particularly with the new electronic natural gas kits currently available in the market. This pressure is critical on full demand applications. Generally, an attempt is made to hold the pressure on the regulator at 100 PSI for low compression engines and four cycle engines. As long as a vehicle is equipped with a system designed for 100 PSI, it will operate as well or better than its gasoline or diesel counterpart. This occurs with heavy-duty and light-duty vehicles alike.

The 3306 Caterpillar Natural Gas Engine Series 50 Detroit Diesel, the 460cc Ford and the 302cc Ford engines are being used in METRO's fleet of vehicles. These are low pressure systems. These fuel delivery systems on the vehicles require the ability to vent the tanks during fueling. Although this procedure is not necessarily used in all refueling efforts. Yet, if the pressures in the tanks are high or higher than the pump pressure from the station itself, venting will have to occur prior to refueling.

Time is critical to the refueling process of a vehicle. With LNG, METRO has been able to fuel vehicles within an eight minute time span. The eight minutes is believed to be required by virtue of the large number of vehicles that have to be refueled each evening at the various METRO facilities. The significance of this lies in the fact that it equals the same fueling time required for diesel powered vehicles.

As a result of early experiences in dealing with LNG, assumptions regarding the saturation of LNG were found to vary in the METRO project. The prevailing notion of saturation (pressurization caused by a rise in temperature of the fuel) of LNG in the on-board fuel tanks to the pressure required for delivery to the engine (e.g. 300 PSI) eliminates the requirement for a pump system, or pressure building system was found to be questionable. The METRO findings suggest that three things occur when pressurization of the LNG to 300 or 350 PSI for delivery to the PING engine, or pressurizing the system to the 100 PSI "required for the low compression engine application..." The following occurrences appeared to result from the saturation of LNG in the on-board fuel tanks to the pressure required for delivery to the engine:

• Reduction in vehicle range due to the expansion that occurs to the LNG upon pressurization with resultant decrease in usable fuel;

• Dramatic reduction in hold time with the tanks themselves. Hold time is defined as the period between fueling and the build up of pressure in the tanks until venting of boil off occurs. Houston METRO required an eight day hold time prior to the boil off, or venting. This could not be accomplished in any of the applications attempted by METRO in pressurizing the LNG because the pressure build up was faster.

• Pressurization of the tanks to the required PSI from the fuel station increases the fueling time dramatically. There are times when this refueling technique requires as much as 30 minutes, which was unacceptable in METRO's operation. Additionally, attempts to balance out the system present challenges that may be difficult to overcome. Further details on venting can be found in the full METRO report on the LNG project.

4.3 Fuel Stations

Fuel station designs are unique in themselves since no fuel stations have been built for LNG vehicles. An review of the state-of-the-art in this regard reveals that a great deal of technology development has occurred. As of 1993, Houston METRO has built two fuel stations, with several more in conceptual engineering or design stage. These stations are set up for eight minute fuel transactions because of operational necessity. The stations are designed to capture the vent gas, completely monitor the fueling and venting in order to record the amount of gallons used by each vehicle. The stations include multiple lanes for fueling, and have a storage capacity of 20,000 gallons plus room for expansion as the number of buses in the fleet increases. Fueling lines and nozzles themselves are unique for fast hook-up and removal of the nozzle itself.

The existing LNG stations are located outdoors, completely separated from diesel fueling and other activities (Figure 5). Future LNG stations will be integrated into existing diesel fuel lanes, according to the report,"Safe Operating Procedures for Alternative Fuel Buses," (*TRB Report, TCRP Synthesis* 1, 1993, p. 26).

4.4 Safety Codes, Facility Modifications, and Training

At the end of 1993, 334 LNG fueled buses had been purchased by Houston METRO. A key issue permeating all efforts to convert the transit fleet to liquefied natural gas was safety. Houston Metro placed safety as a priority as it phased LNG into its bus operations. When the fuel conversion project began, there were few codes applicable to LNG in a transit operation. In the absence of safety codes particularly tailored to LNG, the Houston Metropolitan Transit Authority of Harris County adopted safety regulations followed by the Texas Railroad Commission (TRC) for vehicle fuel systems. Regulations of the TRC were also used as a guide for the construction of LNG fuel stations. Use of these regulations and strict adherence to fire codes of the City of Houston served as a guide for the development and implementation of safe operating procedures.

Figure 5. West LNG Station

Source: Photographs supplied by <u>Houston METRO</u>, 1995.

Although facility modifications were not required for integrating LNG into bus operations, Houston METRO made the decision to upgrade the fire prevention design of their maintenance facilities. Methane detectors, increased ventilation in response to methane detection, and explosion-proof heating and other equipment were incorporated into the facilities used for LNG bus operations.

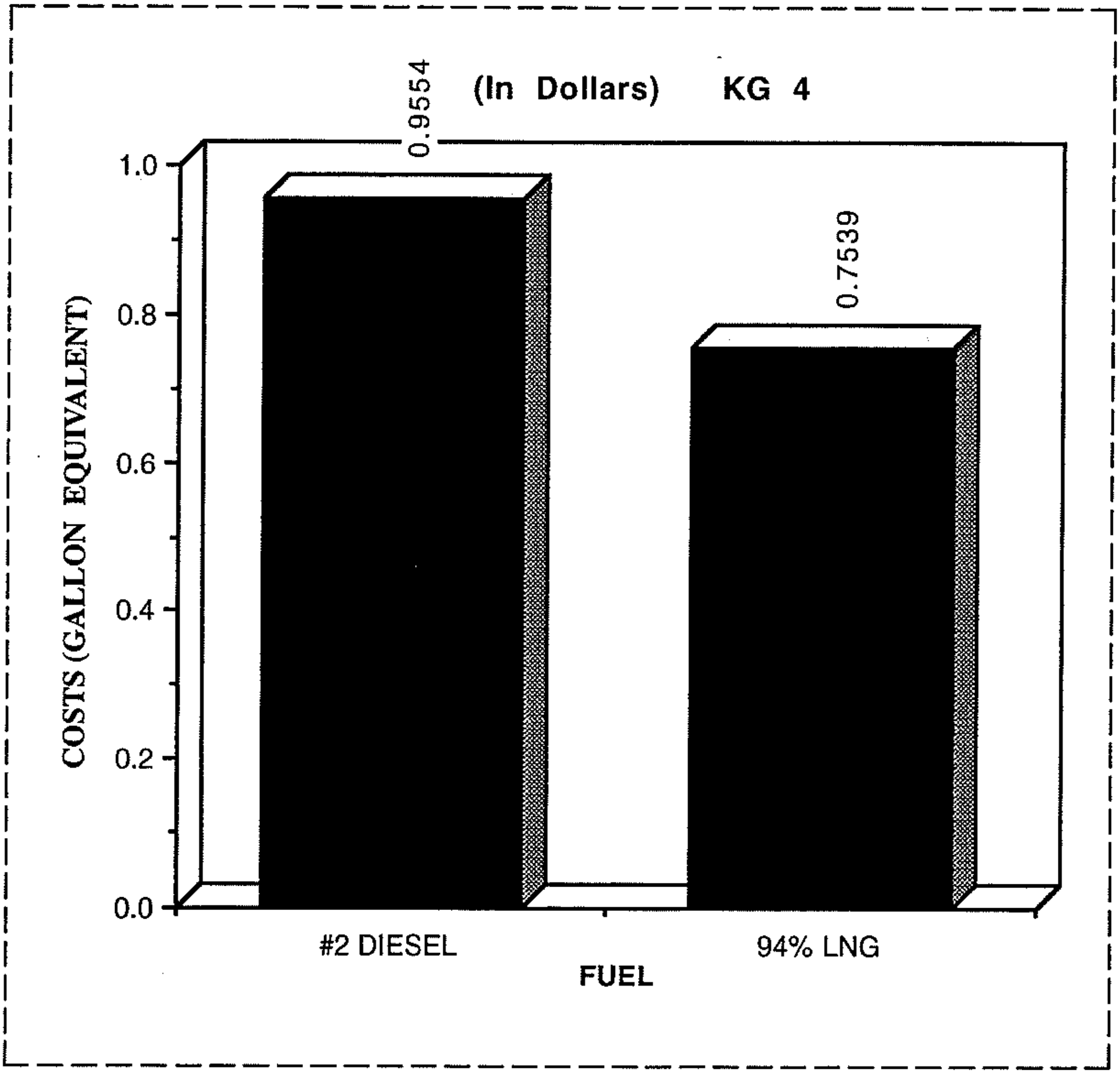
Another critical issue associated with the fuel conversion project was safety training. A structured program of training was developed and implemented. Operators, mechanics, and cleaners/fuelers were required to take safety training. Training courses consisted of a 4-hour classroom session. The training program included a four-step program for mechanics; an introductory class and hands-on training for cleaners/fuelers; and a four-step program, from introduction to technical training for mechanics. To augment safety training, handouts on safety rules and requirements are made available to all training recipients. In addition, an on-going series of "Technical Bulletins" was distributed, covering detailed service and safety topics. Many employees were trained in the Texas Railroad Commission's safety program for compressed natural gas. One serious accident involving a fire and two other minor fires have occurred since the conversion process began. To address these problems, new procedures were established, requiring a cool down period before removal of the mixer. Houston METRO uses a training trailer, which is essentially a bus shell showing the engine and the fuel delivery system.

Mandatory protective gear for fuelers during fueling consisted of a full face shield (incorporating tight-fitting goggles), full-length gloves, and a full-length apron. Houston METRO found that loose-fitting protective clothing provides the greatest safety, since it can be removed more quickly than tight clothing. This is a safety advantage in the case of LNG being spilled on or inside the clothing. Newly designed cryogenic protective gloves and clothing are being evaluated constantly by manufacturers.

Other safety concerns pertained to the on-board fuel system. Cryogenic fuel systems are particularly susceptible to leaking at the joints. Leaking at the joints are caused by temperature cycling and thermal expansion. Welds are preferred when feasible. Stainless steel compression fittings have also proven reliable.

On-board fuel systems for LNG "are different from those for other fuels." A key safety element is a pressure relief valve that allows venting of vapor if the design pressure of the storage tank can be reached. The "venting of vapor should not occur in normal operation, as pressure rise in the tank resulting from heat transfer is offset by consumption of fuel," according to the *TRB Report* (1993:28).

Figure 6
Fuel Cost Comparison



Problems pertaining to LNG engine technology are being corrected as they occur. For example, the problem of sticking valves was corrected by reinstalling new re-manufactured valves that are currently being developed in England. There were no complaints about fuel efficiency.

4.5 Fuel Costs Associated with Conversion

A comparison of cost associated with the LNG fuel conversion project is shown in Figure 6. The figure illustrates that there are savings involved in the fuel itself. However, these savings can easily be diminished by additional taxes on LNG without a corresponding increase in diesel fuel.

Figure 7
LNG Fuels Specifications

	"REGULAR" LNG	"PREMIUM" LNG
Methane	94% min.	99.5% min.
Ethane	2.75% max.	.5% inclusive of all other substances
Propane	.9% max	
Water	0% max.	
Nitrogen	.5% max.	
Total Sulphurs	2.5 mg/m ^{3} max.	
Hexanes	0% max.	0 % max.
Co_2	0% max.	0 % max.

Source: Houston METRO, October, 1993.

To be sure, any increases in fuel taxes would probably affect both, with natural gas being affected the least. Texas currently has a mandatory sticker which must be displayed in the window of all vehicles utilizing natural gas. The cost of a sticker for a full size 40' bus is over 400 dollars. Cost for support vehicles such as pick-up truck types and passenger cars is dependent on vehicle weights and miles driven, according to the METRO report (1994).

Figure 7 shows fuel specifications of regular LNG. Regular LNG is composed of 94 percent (Min) Methane, 2.75% (Max) of Ethane, 0.9% mg/m (Max) of sulphur. Sulphur is calculated per gallon and 2.5 Mg/m is the maximum limit one can add. Figure 8 shows fuel consumption of Premium LNG which is composed of 99.5% (Min) of Methane and 0.5% of other properties.

Figure 8
LNG Fuel Comparison

	#2 DIESEL	94% LNG
Base	\$.5370	\$.3282
Feed Stock	None	.1508
Additive	.0059	None
*Fed Tax	.0085	None
Diesel equiv mult	None	1.4500
Sub-total	\$.5514	\$.6990

*Environmenal, underground water, superfund

Source: Houston METRO, October, 1993.

It includes all substances like Ethane, Propane, Water, Nitrogen and Sulphur). Figure 9 compares costs between two fuels: LNG and diesel. The #2 Diesel costs $0.955 per gallon equivalent and 94% LNG costs $0.7539 per gallon equivalent (inclusive of both federal and state tax). Figure 10 combines data contained in Tables 8-9 to show total cost per gallon equivalent.

Figure 9
LNG Fuel Cost Comparison

	#2 DIESEL	94% LNG
Cost/Gal	$.5514	$.6990
State Tax	.2350	.0444
*Trap Degradation (4%)	.0290	NONE
Low Sulfur Aromatics (CAA)	.1400	NONE
Total (Cost/Gal Equiv)	**$.9554**	**$.7434**
Sub-total		

*NYCTA Experince

Source: Houston METRO, October, 1993.

Figure 10
LNG Fuel Cost Comparison

	#2 DIESEL	94% LNG
Base	$.537	$.3282
Feed Stock	None	.1508
Additive	.0059	NONE
Federal Tax*	.0085	NONE
Diesel Equiv. Multiplier	NONE	1.450
Cost per gallon	.5514	.6990
Trap Degradation (4%)**	.0290	NONE
LOW SULFUR/ AROMATICS (CAA)	.1400	NONE
Total (cost per gallon equivalent)	.7204	.6990

*Environmental, underground water, superfund
** Superfund NYCTA Experience

Source: Houston METRO, October, 1994.

There appears to be some dollar savings in the use of LNG fuel, even when expenditures for taxes are considered. Such savings are quickly eliminated, however, by capital costs associated with vehicle modifications and special equipment required for the alternative fuel. A major benefit is found in clean emissions that contribute to clean air. To maximize any benefits will require "trap technology development" in order to comply with emission standards which will also entail major capital costs. For LNG to be the most cost effective, continued developments in technology will have to be considered.

In a report by Argonne National Laboratory's Energy Systems and Decision Information Systems Divisions (1994), summary data are provided on the characteristics of alternative fuels and alternative-fuel vehicles. Data relative to costs indicate that fuel cost for natural gas is approximately there-fourths that of gasoline. Local utility rates vary. Fuel conversion costs have been found to range from $2,700 to $5,000 per vehicle. A manufacturer's extra price premium can be in the range of $3,500 to $7,500. In addition, users may need to purchase service and diagnostic equipment if access to commercial CNG/LNG vehicle maintenance facilities is not available. *(Argonne Laboratory, U. S. Department of Energy, 1994: pp. 22-23).*

4.6 Fuel Cost Comparisons

The Metropolitan Transit Authority of Houston and Harris County (METRO) tested a Detroit Diesel PING engine extensively at the Federal bus testing site in Altoona, Pennsylvania. During these tests, fuel usage was monitored very closely throughout the duration of the testing period. Comparisons were made between a natural gas configuration and a straight diesel configuration. The results of the tests are illustrated in Table 8.

Table 8
FUEL ANALYSIS FROM ALTOONA TEST*

	Diesel	LNG
• Central Business District	6.25 MPG.	.60 MILE/LB.
• Arterial	11.25 MPG.	.59 MILE/LB.
• Commuter	16.34 MPG.	1.09 MILE/LB.
AVERAGE	11.51 MPG.	.76 MILE/LB.

** Averages are based on four (4) runs. Percent difference from the average ranged from -3.98% to 1.33%.*

Using the LNG vs. diesel example of the Altoona experience, a bus with 100 gallons of diesel used at 3.9 mpg will have a 390 mile range. An LNG bus with a range of 390 miles @ .76 mi/ lb. would require 525.58 lb. LNG or 148.05 gallons. The ratio of LNG gallons to diesel gallons is 1.48 to 1. The LNG substitution for the diesel portion was based on BTUs, according to the METRO (1993) case study. As indicated earlier, the cost comparisons included consideration for the BTU contents when LNG was compared with METRO's #2 diesel fuel. METRO estimated that it would take 1.555 gallons of LNG for every gallon of diesel fuel. The tests conducted at Altoona confirmed Houston METRO's experience. Continued monitoring was performed to determine the extent to which 1.45 gallons of LNG would equal to one gallon of #2 diesel. Projections indicate that if the ratio continues, cost savings will be further enhanced. Testing of buses at the Altoona site continued through 1993.

A comparison of costs for Electric, Methanol, Ethanol, Natural Gas, and Propane vary. For instance, an analysis of the *electric vehicles* indicates that each battery replacement equals 15-20% or more of original vehicle cost. New electric vans costs four to five times more than comparable gasoline-powered vans, according to a study by Argonne National Laboratory (1994: 16). The findings indicate that electricity costs no more than, and likely less than, gasoline . The charging facility needed may require only minimal costs. As with other fuels, there will be some costs associated with training, the purchase of service and diagnostic equipment if access to commercial electric vehicle maintenance facilities is not available.

Fuel costs for Ethanol (E85) costs about twice what gasoline costs. There is some evidence to suggest that E85 costs up to $250 greater than gasoline-fueled vehicles, due to special fittings. Methanol (M85) fuel cost, like that of Ethanol, is about one and one-half times that of gasoline under the current taxing structure. M85 vehicles cost up to $250 greater than gasoline-fueled vehicle, due to special fittings. Vehicle costs for Ethanol and Methanol are similar.

A report commissioned by the Office of Technical Assistance and Safety, Federal Transit Administration (FTA), provides a compilation of both current and historical fuel cost information. The data confirm that fuel costs vary over time and by location. William J. Sheppard of Battelle (March 8, 1993) summarized data on several alternative fuels, including methanol, ethanol, natural gas, LPG-Propane, gasoline, and diesel. The cost for LNG when compared to diesel fuel, i. e., ratio of energy costs, was 1.44; cost with liquefaction, (based on a study by Constable, et. al.,) was established as 6.41. Table 9 reveals a comparative breakdown of costs for "typical price at source/ delivered; energy costs at source/delivered, cost with compression/liquefaction; and cost compared to diesel fuel, ratio of energy costs."

Table 9
Alternative Fuel Data Summary: Cost Information
See accompanying glossary of explanations of terms

	Methanol	Ethanol	Naural Gas	LPG-Propane	Gasoline	Diesel Fuel
Typical price at source $/gal	0.40 (23)	1.33(24)	1.82 $/MM Btu (25) based on HHV	0.32(26)	0.56(27)	0.58(28)
Typical price, delivered to large user, $/gal	0.50(29)	1.40(30)	2.62 $/MMBtu (31) based on HHV	0.42(32)	0.66(33)	0.61(34)
Energy cost at source, $/GJ	6.71(35)	16.53(36)	1.91(37)	5.94(44)	5.34(45)	4.45(46)
Energy cost delivered, $/GJ	8.37(41)	17.40(42)	2.74(43)	N.A.	N.A.	N.A.
Cost with compression, $/GJ	N.A.	N.A.	3.84(47)	N.A.	N.A.	N.A.
Cost with liquefaction, $/GJ	N.A.	N.A.	6.41(48)	N.A.	N.A.	N.A.
Cost Compared to diesel fuel, ratio of energy costs	1.88	3.91	CNG: 0.86 LNG: 1.44	1.341	1.20	1.00

Source: Battelle, Alternative Fuel Cost Summary. Prepared by William J. Sheppard For OTAS. FTA, March, 1993.

Data in this case study were compiled on a monthly basis for fuel consumption by selected vehicles (Marco Polo and Ikarus), cost per mile, cost per gallon, fuel purchases and personnel. Table 10 indicates that cost per mile for the vehicles varied from month to month. The totals, as indicated by the asterisk, include cost per gallon. The data also indicate that fuel consumption for the Marco Polo and Ikarus buses that were used in the case study remained relatively consistent ranging from 13,000 gallons to 23,000 gallons. It was determined by Houston METRO, during the periods in question, that there was a certain product loss with the temporary storage and delivery facilities. This accounts for the fact that the total gallons used (17,131) in August, 1992 were more than the figure used for calculation of (11,392) in its Monthly Status Report on Alternative Fuels during the period.

An examination of data on fuel purchases (Table 10) shows that some fluctuation occurred throughout the test period in dollar amounts along with the respective gallons purchased. A similar pattern can be observed in the personnel category where the total staff members involved in the alternative fuels project ranged from six to eight individuals.

Unscheduled maintenance, fuel costs and consumption data were collected during the period, October, 1991 through December, 1992. As indicated in Table 11, the accumulated mileage is recorded in actual miles taken from LNG, CNG, and diesel vehicles. The CNG data are only included in October and November, 1991. The highest mileage occurred in September, 1992 (71,846), and the lowest occurred in October of 1991 (30,420).

A further examination of Table 11 will reveal the results of road calls, safety incidents, and diesel emission test results. Data taken from LNG and controlled vehicles indicated that the highest

Table 10
Detailed Monthly Fuel Cost and Consumption Data, LNG Demonstration Project, Houston - Metro 1991-1992

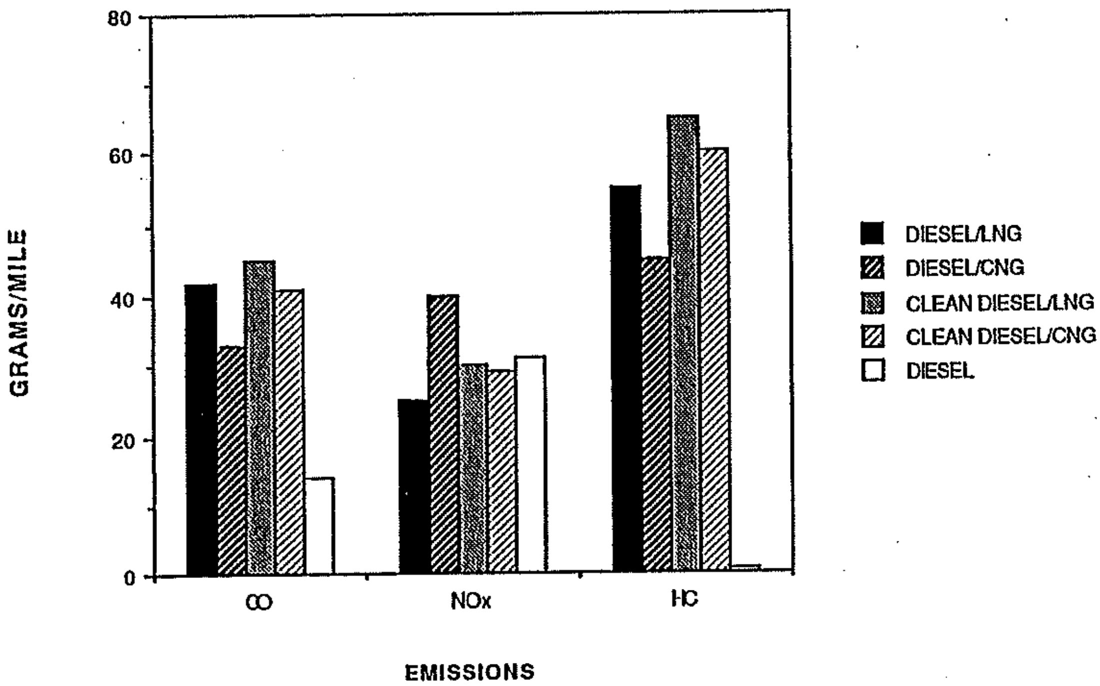
Date	Fuel Consumption (Marco Polo & Ikarus Vehicle In Gallons	Cost per Mile Sept - 91 -Jul 92 Cost per Gallon July 92 - Dec 92	Fuel Purchases (STATS Only)	Personnel
	STATS 11,500 Diesel 2,441 Total 13,941	STATS .91 CNG .69 Diesel .22 Total $1.82	STATS $13,800.00 (11,500 gallons) CNG $3,948.00 Total $17,748.00	Manager 1 Supervisor 1 Fuels Technician 2 Testing Technician 2 Total 6
	STATS 12,265 Diesel 2,008 Total 14,273	STATS Vehicles .37 CNG .82 Diesel .19 Total $1.38	STATS $10,083.00 (12,625 gallons) CNG $3,948.00 Total $14,031.00	Manager 1 Supervisor 1 Fuels Technician 2 Testing Technician 2 Total 6
	STATS 11,067 Diesel 2,517 Total 13,584	STATS .41 Diesel .18 Total .59	STATS $5,040.00 (5,600 gallons)	Manager 1 Supervisor 1 Fuels Technician 2 Testing Technician 2 Total 6
	STATS 12,400 Diesel 2,083 Total 14,483	STATS .37 Diesel .19 Total .56	STATS $11,504.00 (12,784 gallons)	Manager 1 Supervisor 1 Fuels Technician 3 Testing Technician 2 Total 7
	STATS 10,780 Diesel 3,320 Total 14,100	STATS .61 Diesel .50 Total $1.11	STATS $12,155 (13,222 gallons)	Manager 1 Supervisor 1 Fuels Technician 3 Testing Technician 2 Total 7
	STATS 12,566 Diesel 3,232 Total 15,798	STATS .61 Diesel .50 Total $1.11	STATS $12,490.20 (13,878 gallons)	Manager 1 Supervisor 1 Fuels Technician 3 Testing Technician 2 Total 7
	STATS 11,908 Diesel 3,364 Total 15,272	STATS .61 Diesel .50 Total $1.11	STATS $5,848.20 (6,498 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
	STATS 9,704 Diesel 3,912 Total 13,616	STATS .58 Diesel .51 Total $1.09	STATS $11,008.68 (13,108 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
	STATS 12,300 Diesel 5,102 Total 17,402	STATS .59 Diesel .53 Total $1.12	STATS $10,234.80 (13,121 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
	STATS 15,486 Diesel 5,812 Total 21,298	STATS .54 Diesel .53 Total $1.07	STATS $11,136.82 (14,322 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
	STATS 17,131 Diesel 7,381 Total 24,512	STATS .79 Diesel .80 Total $1.59*	STATS $19,756.88 (24,758 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
	STATS 16,560 Diesel 7,050 Total 23,610	STATS .80 Diesel .81 Total $1.61*	STATS $7,182.13 (8,933 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
	N/A	N/A	N/A	N/A
	STATS 17,606 Diesel 7,579 Total 25,185	STATS .82 Diesel .79 Total $1.61*	STATS $23,895.77 (19, 671 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8
December, 1992	STATS 12,497 Diesel 6,431 Total 18,928	STATS .82 Diesel .79 Total $1.57*	STATS $22,795.18 (26,412 gallons)	Manager 1 Supervisor 1 Fuels Technician 4 Testing Technician 2 Total 8

***Totals are cost per gallon**

Table 11
Detailed Monthly Data on Unscheduled Maintenance, Houston Metro LNG Project, 1991-1992

Date	Accumulated Mileage Actual	Maintenance (Road Calls)	Safety Incidents	Diesel Emission Test Results
October, 1991				
	LNG 8,216 CNG 6,690 Diesel 15,514 Total 30,420	LNG Vehicles 8 Control Vehicles 3 CNG Vehicles 6 Total 17	Facility 0 Vehicles 1 Total 1	Failures (20%+) 8 10-19% 10 Pass (0-10%) 50
November, 1991				
	LNG 12,265 CNG 5,310 Diesel 15,737 Total 33,312	LNG Vehicles 8 Control Vehicles 2 CNG Vehicles 8 Total 18	Facility 0 Vehicles 0 Total 0	Failures (20%+) 14 10-19% 38 Pass (0-10%) 96
December, 1991				
	LNG 17,730 Diesel 18,705 Total 36,435	LNG Vehicles 24 Control Vehicles 2 Total 26	Facility 0 Vehicles 0 Total 0	Failures (20%+) 10 10-19% 35 Pass (0-10%) 105
January, 1992				
	LNG 22,831 Diesel 14,160 Total 36,991	LNG Vehicles 6 Control Vehicles 6 Total 12	Facility 0 Vehicles 0 Total 0	Failures (20%+) 6 10-19% 29 Pass (0-10%) 88
February, 1992				
	LNG 18,877 Diesel 18,760 Total 37,637	LNG Vehicles 19 Control Vehicles 6 Total 25	Facility 0 Vehicles 0 Total 0	Failures (20%+) 4 10-19% 12 Pass (0-10%) 42
March, 1992				
	LNG 22,823 Diesel 17,433 Total 40,256	LNG Vehicles 20 Control Vehicles 7 Total 27	Facility 0 Vehicles 0 Total 0	Failures (20%+) 6 10-19% 28 Pass (0-10%) 58
April, 1992				
	LNG 19,901 Diesel 19,728 Total 39,629	LNG Vehicles 12 Control Vehicles 4 Total 16	Facility 0 Vehicles 1 Total 1	Failures (20%+) 16 10-19% 17 Pass (0-10%) 61
May, 1992				
	LNG 16,721 Diesel 22,214 Total 38,935	LNG Vehicles 12 Control Vehicles 6 Total 18	Facility 0 Vehicles 0 Total 0	Failures (20%+) 21 10-19% 25 Pass (0-10%) 57
June, 1992				
	LNG 23,436 Diesel 24,807 Total 48,243	LNG Vehicles 22 Control Vehicles 17 Total 39	Facility 0 Vehicles 0 Total 0	Failures (20%+) 16 10-19% 27 Pass (0-10%) 40
July, 1992				
	LNG 35,233 Diesel 26,358 Total 61,591	LNG Vehicles 31 Control Vehicles 17 Total 48	Facility 0 Vehicles 0 Total 0	Failures (20%+) 10 10-19% 28 Pass (0-10%) 44
August, 1992				
	LNG 34,901 Diesel 34,142 Total 69,043	LNG Vehicles 16 Control Vehicles 8 Total 24	Facility 0 Vehicles 0 Total 0	Failures (20%+) 19 10-19% 34 Pass (0-10%) 66
September, 1992				
	LNG 38,430 Diesel 33,416 Total 71,846	LNG Vehicles 33 Control Vehicles 14 Total 47	Facility 0 Vehicles 0 Total 0	Failures (20%+) 19 10-19% 41 Pass (0-10%) 45
October, 1992				
	N/A	N/A	N/A	N/A
November, 1992				
	LNG 33,107 Diesel 26,884 Total 59,991	LNG Vehicles 31 Control Vehicles 12 Total 43	Facility 0 Vehicles 0 Total 0	N/A
December, 1992				
	LNG 35,106 Diesel 32,466 Total 67,572	LNG Vehicles 41 Control Vehicles 15 Total 55	Facility 0 Vehicles 1 Total 1	N/A

Figure 11
CARBON MONOXIDE (CO), OXIDES OF NITROGEN (NOx) AND HYDROCARBON EMISSION FOR PILOT INJECTION CNG AND LNG BUSES COMPARED TO DIESEL CONTROL BUSES



road calls occurred in December of 1992 and the lowest occurred earlier in January of the same year. Also, during the test period there were only three vehicle safety incidents. The capacity testing program, illustrated in Table 11, was for diesel fueled vehicles only. Data were not included from October to December of 1992. Failures occurred when test results were 20% and above, while 10% or less was considered passing inspection tests.

4.7 Carbon Monoxide (CO) Emissions Comparisons

A recent report to Congress for Fiscal Year 1993 by the U. S. Department of Energy (1994) provides results from transit bus projects, including Houston METRO. Results from selected representative projects that are operating buses on compressed natural gas, liquefied natural gas, methanol, and ethanol were used. The projects were chosen on the basis of completeness of the available data and of the "representative-ness" of bus operations for other locations.

Compressed natural gas and liquefied natural gas buses differ only in their fuel storage/ dispensing systems. There are a number of different engine fuel systems that can be used with both compressed natural gas and liquefied natural gas. All of the compressed natural gas buses were equipped with spark-ignition engines. Several of the liquefied natural buses used in the Houston Metropolitan Transit Authority project are pilot-injection natural gas (PING) engines that were supplied by Detroit Diesel Corporation. Whereas, several of the other pilot -injection natural gas engines were emission-tested using the West Virginia Transportable Emissions Laboratory.

Figure 11 reveals the emissions of carbon monoxide (C)), oxides of nitrogen (NOx), and hydrocarbon for six similar buses with diesel/liquefied natural gas, diesel/compressed natural gas,clean diesel/liquefied natural gas, and clean diesel/compressed natural gas pilot-injection natural gas engines, as well as diesel and clean-diesel control buses. It should be noted that the carbon monoxide (CO) emissions for the pilot-injection natural gas engines are significantly higher than those for the diesel control vehicles. Oxides of nitrogen (NOx) emissions are fairly consistent across the range of engines. The higher oxides of nitrogen (NOx) emissions for the diesel/ compressed natural gas engine and the lower oxides of nitrogen (NOx) emissions for the diesel/ liquefied natural gas system are probably due to a different in the engine calibrations rather than any fundamental different in liquefied natural gas versus compressed natural gas fuels. As would be expected, the pilot-injection natural gas engines exhibit extremely high total hydrocarbon emissions (*DOE Report,* September, 1994, pp. 5-11-12).

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

The fuel economy of the six buses tested, including Houston METRO, is comparable, with the exception of the two diesel/compressed natural gas buses. The difference in fuel economy for the diesel/compressed, illustrated in Figure 12, could not be readily explained.

4.8 Alternative Fuels in Transition: Proposed Legislative Changes

A 1994 report on the status of alternative fuels in Texas indicated that Texas fleet operators were phasing in alternative motor fuels. The Comptroller's fuel-tax records showed at least 26,650 public and private vehicles were using alternative fuels around the state as of June, 1994. Responding to legal mandates, Texas' state agencies, local school districts and urban transit authorities had begun the enormous task of converting thousands of fleet vehicles to alternative fuels. Transit

Figure 12
PARTICULATE EMISSION AND FUEL ECONOMY FOR PILOT INJECTION COMPRESSED NATURAL GAS AND LIQUEFIED NATURAL GAS BUSES COMPARED TO DIESEL CONTROL BUSES

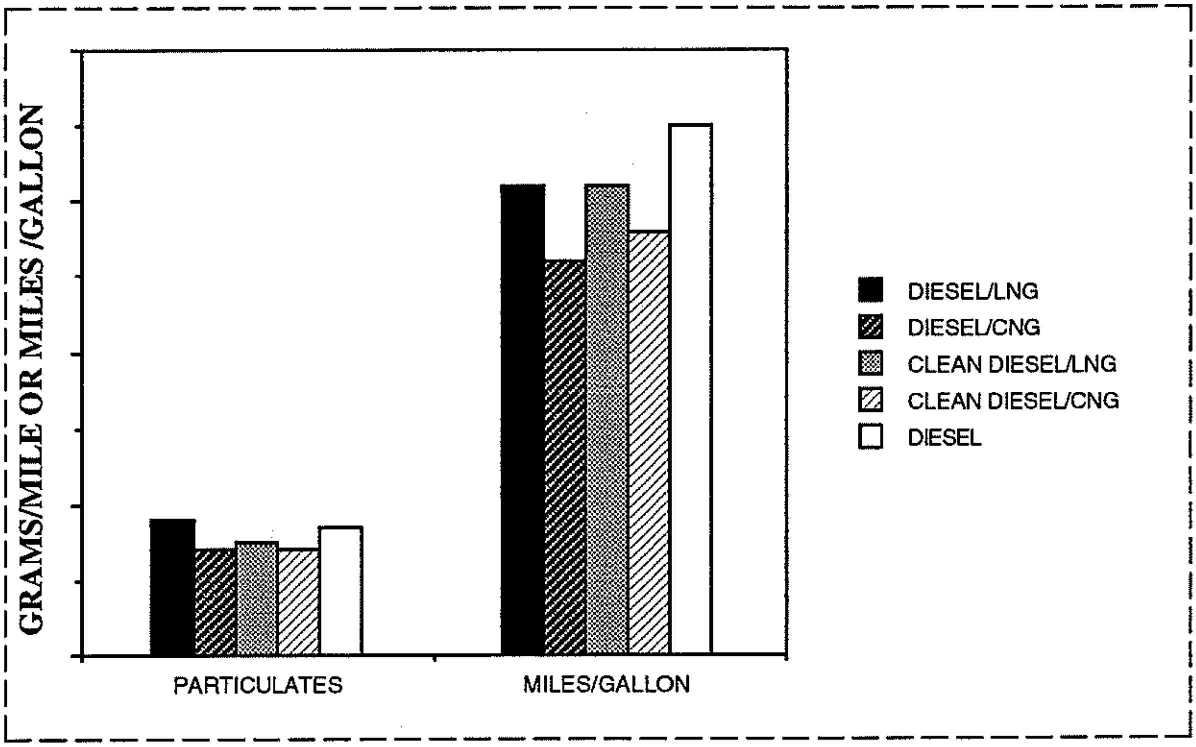


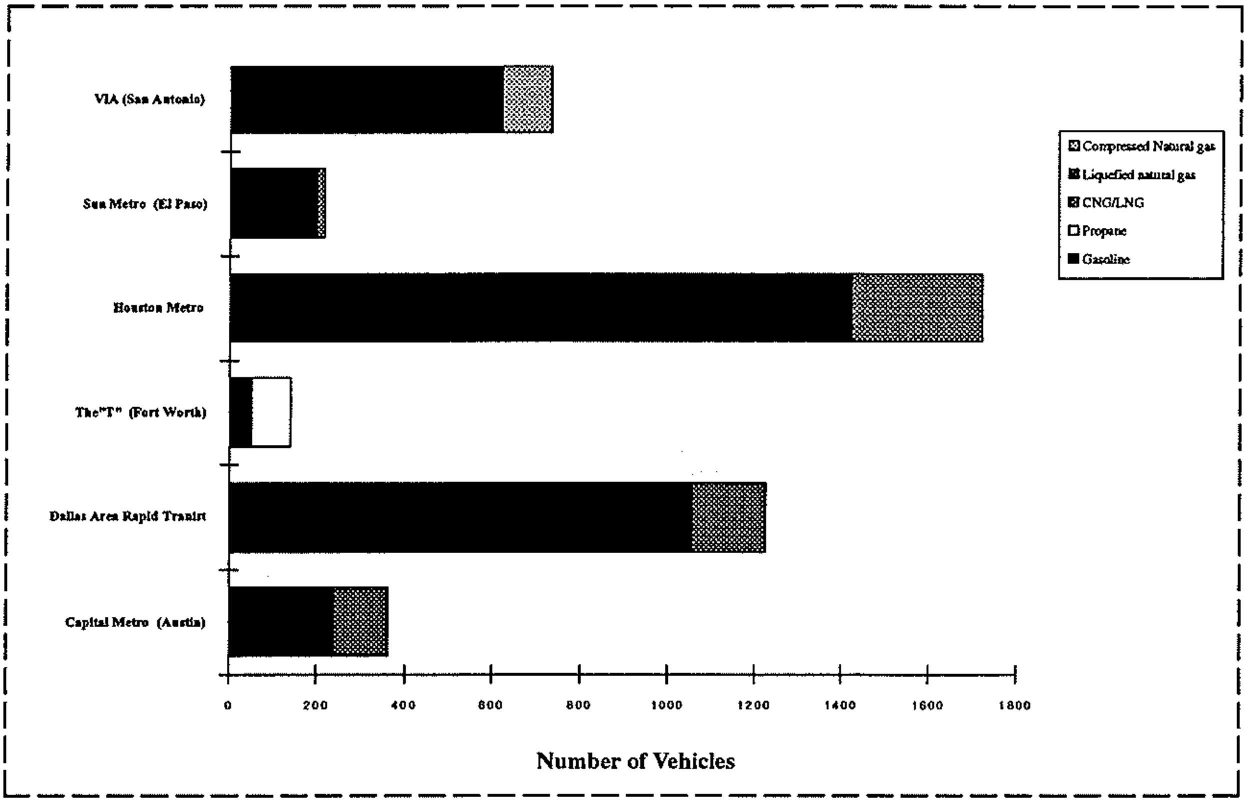
Table 12
Status of Texas Transit Authorities

	Total Buses	Alternate- Fueled Buses
Dallas	862	2
Ft. Worth	159	44
Austin	331	72
San Antonio	548	0
El Paso	213	75
Corpus Christi	75	5
Houston	1,124	282

San Antonio has 177 vans (handicap) of these 112 are alternate-fueled. (They have just received alternate-fueled cars)

Source: Barker, Bill, <u>Transit Utilization of Alternative Fuels in Texas.</u> A Presentation To The Texas Public Transportation Conference, April 26, 1994.

Figure 13
FLEET VEHICLE USE BY TRANSIT AUTHORITIES, 1994



systems in the six largest metropolitan areas in Texas were operating an estimated 800 alternative-fueled vehicles (AFVs) and plans were in place to acquire an additional 600 in the next several years. The current status of alternative-fueled buses operated by transit authorities in Texas is outlined in Table 12.

At this time, there is growing concern about requirements mandated by state and federal laws. Business groups concerned about the costs of fleet conversion and the availability of alternative fuels and vehicles have proposed changes in general requirements and implementation plans. In July, 1994, for example, the Texas Natural Resource Conservation Commission (TNRCC) announced that it was deferring its decision on authorized fuels until December, 1996, while vehicle emissions tests are conducted. The revision was designed to allow local government and private fleets, as well as school districts with at least 15 but fewer than 50 buses, to use reformulated gasoline and low sulfur diesel.

Another problem pertains to potential user groups. Widespread consumer acceptance of alternative fuels is hampered by low prices of traditional fuels and the generally lower mileage performance of alternative fueled vehicles. Also, emissions testing has not been widely accepted by fleet operators and automobile owners in the state's largest metropolitan areas.

In April, 1995 several bills were filed with the Texas Legislature which were designed to ease restrictions and initiate changes in the state and federal mandates previously approved for implementation. Some of the proposals included changes in the definition of alternative fuel, the exclusion of mass transit from the proposed legislation. The proposed changes were challenged by environmental groups. Environmentalists noted that the changes in the Alternative Fuels Act of 1989 will hinder the state's attempt to improve air quality through emissions standards.

The proposed changes and alterations in the mandates initiated to comply with the Clean Air Act Amendments (CAAA) have adversely impacted the alternative fuel conversion project at the Metropolitan Transit Authority of Houston and Harris County. On March 21, 1995, the General Manager of Houston METRO advised the Transit Operations Committee of the Board of Directors that consideration should be given to changing 85 mid-size buses, that were running on LNG, back to diesel. Houston METRO has an estimated 293 buses and vans running on LNG, or 21 percent of its 1,391-vehicle transit fleet. This figure represents a decrease from data contained in *Fiscal Notes* (September, 1994) published by the Texas Comptroller's Office. Data contained in a report on "Transportation in Transition" indicated that Houston METRO had 1,423 buses run on gasoline or diesel. Of this total 301 were using LNG (*Fiscal Notes, 1994:5).*

The aggressive program to convert buses from diesel to LNG clean-burning fuel has been halted, at least temporarily by Houston METRO. The slowdown in the fuel conversion initiative appears to be in response to falling prices for diesel fuel compared to natural gas, and the pending legislation providing for the loosening of state pollution regulations. In a study by Booz Allen (May, 1992) used a cost of diesel fuel at $.75/gallon and LNG at $.46/gallon ($.69 equal). This study provided a rationale for replacing diesel with LNG. The trends in diesel fuel prices, beginning in 1991, are indicated in Table 13.

Table 13
History Of Diesel Fuel Prices

MONTH	1991	1992	1993	1994
Aug	0.731	0.829	0.720	0.719
Sep	0.778	0.810	0.751	0.708
Oct	0.777	0.840	0.788	0.698
Nov	0.902	0.790	0.785	0.735
Dec	0.824	0.770	0.753	0.706

Source: <u>Houston METRO</u>, October, 1994.

Table 14
March 1, 1995 Fuel Costs

Actual LNG Price	Equal Energy Price/LNG	Actual Diesel Price
0.510	0.830	0.692

It is costing Metro $.138 to replace each gallon of diesel fuel with LNG at this time.

Source: Houston METRO, October, 1995.

Table 15
March 1, 1995 Fuel Costs

If LNG cost is	Then Diesel Break-even is
0.30	0.489
0.35	0.571
0.40	0.652
0.45	0.734
0.50	0.815
0.55	0.897
0.60	0.978

Source: Source: Houston METRO, October, 1995.

Table 16
Fuel Economics of Proposed LNG Fleet
Annual Costs at March 1, 1995 Prices

Transit - 50 units	
Annual average mileage	40,000
If diesel	$411,216
If LNG/diesel	$452,556
Variance	$41,340
Commuter - 113 units	
Annual average mileage	25,000
If diesel	$514,489
If LNG/diesel	$576,526
Variance	$62,037

Additional annual cost above diesel = $103,377.00

Source: Houston METRO, October, 1995.

As of March 1, 1995, the actual fuel price for LNG was 0.510, with an equal energy price of 0.830, compared to 0.692 for diesel. (See: Table 14). Costs for LNG compared to petroleum fuel at equal energy are shown in Table 15. Houston METRO has also calculated the annual costs for the LNG fleet, as of March 1, 1995. These data are shown in Table 16. The data indicate that the variance between LNG and diesel for transit (50 units) is $41,340; for commuter (113 units), $62,037. The projected additional annual cost above diesel equal $103,377.

The proposed legislation was revised by the Texas House of Representatives to let fleet vehicles "use any fuel that meets less-stringent federal requirements." The change was also approved by the Texas Senate. What is not clear about the legislation is whether Houston METRO will be permitted to continue to use diesel engines that burn a low-sulfur form of the fuel. If the clean diesel fuel can be used, this will apparently provide the agency with another option besides LNG. With diesel prices falling to 69 cents in March, 1995, Houston METRO was advised that the energy-equivalent of LNG had increased to 83 cents. Since the agency buys about 10 million gallons of diesel fuel each year, the falling price could save money for Houston METRO.

No decision has been made about the future of LNG at Houston METRO. The previous plan will be evaluated on an on-going basis.

4.9 Summary and Future Implications

As the nation continues to pursue the goals of energy independence and ensuring a higher quality of life, extensive research and development is essential in the area of alternative fuels and on alternative-vehicle technologies. This study has examined cost associated with converting diesel-operated vehicles to liquefied natural gas vehicles. More research is needed on the cost efficiencies of alternative fuels.

A central focus this research has been costs associated with alternative fuels development. The sources of information used in the study involved a variety of sources, including a survey of transit agencies known to be using alternative fuels, a review of the state-of-the-art, and a documentation and analysis of a case study of Houston METRO, an agency involved in an alternative fuels conversion project. The practices employed by Houston METRO in assessing absolute requirements in the natural evolution of LNG as a vehicular fuel are summarized in this study.

A summary of major findings follows:

• When compared with other fuels, natural gas appears to be very popular among alternative fuels. Between 1992 and 1993, an estimated 60 operators in the United States and Canada and a total of 899 transit vehicles (including both buses and vans) were using either natural gas or a combination of natural gas and diesel or gasoline. The trend toward increased utilization continues to grow in 1995. Houston METRO had a fleet of over 250 vehicles in 1994. Projections indicate that the number will continue to grow. The cities of Fort Worth, Texas and Sacramento, California have more than 50 natural gas buses. Other cities are placing in service vehicles from a variety of manufacturers.

• Findings of previous studies indicate several factors influenced transit agencies' decisions to use alternative fuels. Factors such as air quality benefits, the need to develop technologies to ensure energy independence in the United States, compliance requirements of the legislative mandate under the Clean Air Act Amendments of 1990, safety, the availability vs. lack of availability of an adequate supply of a particular alternative fuel, safety, and the challenges associated with the involvement with a new technology — were all very influential in the decision making process (TRB, 1993: 33-34). Survey results for this study approximate the findings of the TRB survey included in the study, "Safe Operating Procedures for Alternative Fuel Buses," by Geoffrey V. Hemsley in 1993.

• Major problems encountered by transit agencies involved in the utilization of alternative fuels pertained to high costs, technical difficulties in implementing alternative fuels programs, and the lack of industry maturity. Natural gas is in plentiful domestic supply. What is needed are the necessary facilities to successfully implement such programs. To deal with apparent the lack of sufficient resources in this regard, efforts are being made to specifically address this void in the industry. Liquid Carbonic has begun operating the world's first liquefied natural gas plant designed specifically to produce motor fuel oil. The plant, located in Willis, Texas, produces 100,000 gallons a day for 99.5 percent liquid methane to fuel fleet vehicles such as the metro buses of Austin, Houston, and El Paso in Texas. The plant can store 840,000 gallons of LNG. Deliveries to user terminals are in 11,000-gallon trailer trucks(*METRO* , Vol. 91, No. 1, January - February, 1995: 71).

• Despite the problems experienced by transit agencies and other users of alternative fuels, there is the prevailing belief that they can be solved. Some of the respondents to the survey indicated that the potential benefits outweighed the costs. Some of the benefits that can be realized from the use of alternative fuels include the following: Enhanced public image, increased engine life due to cleaner combustion, reduced costs relative to fuel and maintenance, and better appreciation for conventional fuels.

• There are disadvantages in the daily use of alternative fuels. Previous studies, including the findings of this research, suggest that higher costs, increased complexity, poor range, longer fueling time, lower efficiency, off-site fueling, and limited fuel suppliers are primary disadvantages that must be considered.

• Several findings surfaced from the case study of the Liquefied Natural Gas (LNG) fuel conversion project of Houston METRO. Preliminary data indicate that the LNG combines the low operating cost of natural gas with the on-board storage density of a liquid fuel. Engine and fuel system reliabilities appear to be approaching an acceptable level.

Technical issues of handling the cryogenic liquid are challenging, but are being resolved. Houston METRO's alternative fuels program is still in progress. To this end, it is difficult to reach conclusions about cost efficiency. METRO is working on technology for improving on-board liquid level gauges, for instance. Efforts are also underway to redesign fuel tank systems to allow installation of tanks with configurations other than the present cylindrical design. Different shape tanks can be designed for specific types of vehicles. This may result in better utilization. Applications will include passenger cars, pickup trucks, heavy-duty vehicles and buses. Other efforts include improvements in fuel station design and delivery of the fuel itself. Both short-term and long-term objectives of the Houston METRO project include: Improved metering of the fuel for inventory reconciliation and performance analysis with robotics fueling.

Finally, the Houston METRO project was not launched for demonstration purposes. The intent of the project was to convert the entire fleet to LNG as the primary fuel. As the alternative fuels conversion project continues, particular issues relative to problems or difficulties with alternative fuels will have to be addressed.

There is need to examine a variety of issues that will impact alternative fuels development. Research on strategies for improving operating efficiency should be of interest to a wide range of transit properties. All transit agencies — large and small —share a common interest in controlling higher costs, ensuring durability and reliability of alternatively fueled vehicles; in providing adequate training for users of alternative fuels and staff members in charge of maintenance and operations. Education and on-the-job training will be extremely important to transit agencies. The quality of the equipment, the standardization of equipment, fueling time and complexity, fuel storage, infrastructure development, safety, and the availability of information on the use of LNG — are issues to be addressed also. Of even greater importance will be issues pertaining to the development of codes, standards, and guidelines for successful implementation of LNG and other alternative fuels.

Previous findings regarding alternative fuels suggest the need for research on the following Liquefied Natural Gas (LNG) topics: Storage and handling, fuel delivery systems, vapor handling (i.e., vapor return, re-liquefaction), and odorization. To be sure, research on equipment-related issues should be given a high priority. Much of the research that is in progress reflect early testing and demonstration phases. There is need to expose research results from alternative fuels to practical application. The technologies have not been sufficiently tested to demonstrate cost effectiveness.

Newly developed technologies and innovative practices hold promise for improved operation efficiencies in many areas of transit. Some technologies are available for an array of options, costs, and uses. Energy is one exception since alternative fuels are still in the developmental phase. Research in the area of alternative fuels should build on existing technologies by synthesizing the pros and cons of the various options. The development of a comprehensive document about the most successful technologies and the best practices relative to alternative fuels would be extremely helpful as more and more transit agencies take the alternative fuels route.

The unique characteristics of alternative fuels and vehicles suggest the need for developing appropriate regulations and certification requirements for training technicians who install and maintain alternative fuel components. The U. S. Department of Energy has taken steps in this regard through such training entities as the Institute for Automotive Service Excellence. Curriculum development for such training is critical to the alternative fuels thrust by public and private agencies. Efforts to educate and stimulate future technicians and professionals will enhance public awareness of emerging alternative fuels technology.

5.0 Consumer Awareness and Support for Alternative Fuels

Strategies and techniques for increasing public awareness and consumer acceptance of alternative fuels should be developed and implemented along with efforts to test alternative fuels. There have been instances where consumers besieged elected/appointed officials and the media about problems with mandates by the Environmental Protection Agency (EPA). Complaints range from costs for emission testing to gas fumes that make them nauseous, and other complications such as coughing and skin rashes. Residents of Waukesha, Wisconsin (*Houston Chronicle*, March 5, 1995) indicated that reformulated gas damaged their car engines. Fears abound about the safety of alternative fuels.

In a discussion by the Federal Transit Administration (FTA) of safety issues related to alternative fuel usage, it was noted that liquefied natural gas (LNG) has absolutely no odor, and thus cannot be detected by smell. The extremely low temperature of the fuel requires special handling procedures, as was also revealed in the survey by Houston METRO. The technology for fueling equipment does not yet assure leak-free connections, and the cryogenic nature of the fuel presents cryogenic (freeze) burn hazards for personnel.

Future research should be designed to develop ways for the safe handling of alternative fuels. A hazardous analysis should be performed and used to develop specifications and appropriate written safety procedures for handling alternative fuels such as LNG. FTA advises (*TRB Report,* 1993:44) that "the safe operation of alternative fueled vehicles in the transit environment requires:"

- *Proactive management that focuses on safety.*
- *Qualified design/construction of new or rehabilitated facilities.*
- *Qualified training, certification, and re-training of all workers who may be involved with their operation and maintenance.*
- *Ever present safety consciousness*

Bills have been introduced in Congress and legislatures in various states to halt the program until cost and health concerns are resolved. In Texas, there is a Senate Special Committee on Emissions Testing and Clean Air and a House Committee on Environmental Regulation that have taken steps to scheduled a series of public hearings that will delay the implementation of a state-sponsored inspection and maintenance program and Employer Trip Reduction programs developed in response to EPA-ordered regulations.

5.1 Guidelines and Recommendations

Numerous transit agencies have introduced or plan to introduce alternative fueled vehicles into their operations. FTA Administrator Gordon J. Linton sent a special communication to all transit agencies as early as November, 1993 in which he outlined some of the factors which should be considered in alternative fuel usage. Linton also advised that FTA would distribute guideline documents for facility design, construction, and operation of alternative fueled buses to all FTA grant recipients. Of particular concern to FTA Administrator Linton was the need to initiate appropriate safety precautions associated with alternative fuel usage and the need to carefully assure safe operations.

Based on the survey conducted for this report, previous and subsequent surveys by public and private agencies on alternative fuels, this study recommends the following:

5.1: That a broad-based ***applied*** research program be developed to consider issues that have the potential for minimizing risks associated with operating alternative fueled vehicles. Research on management issues, on the nature and quality of maintenance, fueling, and storage facilities; on regulations and standards to assure appropriate levels of workplace safety; and on maintenance and operations of alternative fueled vehicles.

5.2: That specialized training and retraining programs be developed by selected colleges and universities to ensure the appropriate maintenance and servicing of alternative fueled vehicles.

5.3: To provide support for the previous two recommendations (5.1 and 5.2), a comprehensive public/consumer awareness marketing program should be designed to educate all personnel about the characteristics of and hazards associated with the particular fuel in use by the particular transit agency. Additionally, specific strategies and programs should be developed in order to educate and stimulate interest among the various "publics", including potential users (customers) and the general public.

GLOSSARY

Business Statistics:

Origin The source or raw material for the majority of the fuel supplied in commerce is derived.

US Demand The amount of this fuel consumed in the U.S. in a recent year. These data are intended to indicate the magnitude of the industry in question. The amount given for diesel fuel reflects highway transportation fuel use only and does not include home heating oil.

US Production The amount of this fuel produced in the U.S. in a recent year. Production fluctuates from year to year and the production figures should be considered as being approximate only.

Cost Information:

Typical Price at Source The typical quantity price in a recent year.

Typical Price Delivered to Large User This price is based on price described above, plus the cost of delivery to a user with annual fuel requirements comparable to that of a large transit property.

Energy Cost at Source The cost of the fuel based on the energy content. This cost is based on the cost upon delivery to the port or equivalent. The lower heating value of the fuel (see Fuel Heating Value) is used to calculate the energy cost.

Energy Cost Delivered to Large Users The cost of the fuel based on the energy content. This cost is based on the energy cost at the "source", described above, plus the cost of delivery to a user with annual fuel requirements comparable to that of a large transit property. The lower heating value of the fuel (see Fuel Heating Value) is used to calculate the energy cost.

Cost with Compression The estimated cost of the fuel including the capital and operating costs of compressing natural gas to 3600 psi to supply a 250 bus base. The compression costs depend on the size of the facility, the delivery rate, and especially on the gas supply pressure.

Cost with Liquefaction The estimated cost of liquefied natural gas including the capital and operating costs of liquefaction. The liquefaction costs depend on the size of the facility, the delivery rate, and the type of refrigeration equipment used.

Other Terms:

Fuel Value The amount of energy contained in the fuel. Fuel heating values are listed as higher heating values, HHV, or lower heating values, LHV, depending on whether the latent heat of vaporization of the water formed from combustion of the fuel is considered to be available. If it is, then the higher or gross heating value is used. If the water formed from combustion is not condensed and therefore not considered to be available, then the lower, or net, heating value is used. In USA practice, gross fuel heating values are generally used for all types of energy analysis, except in the transportation industry. In Europe lower or net heating values are more common. In this table fuel values are also given on both a mass and a volume basis, e.g. kJ/kg and kJ/L.

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(2) Only fermentation grade ethanol qualifies for fuel tax credits. Without these credits, prices are much higher.

(3) Natural Gas Annual 1990, DOE/EIA-0131(91) pp. 8,14. Data are for 1991.

(4) Petroleum Supply Annual 1990, Vol. 1 (DOE/EIA-0340~90/1), Tables 15, 17. The data here do not include the propylene content of highway-grade propane from refineries.

(5) Based on gallons of gasohol times 0.10 and total gasoline from Highway Statistics 1990, Federal Highway Administration, FHWA-PL-92-025.

(6) "Chemical Profile—Methanol", Chemical Marketing Reporter, 17 Aug 1992, pp. 50, 17.

(7) Fermentation grade ethanol only; 86 percent is for fuel use currently. "Chemical Profiles—Ethanol", Chemical Marketing Reporter, 25 Mar 1991. pp. 42,37.

(8) 1992 data, Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Table 4.2.

(9) 1992 data, Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Table 3.8. Product listed in DOE report times 0.442, which is the estimated fraction of propane in the DOE LPG designation using composition data from Petroleum Supply Annual 1990, Vol. 1, Tables 15, 17, DOE/EIA-0340(90/1). Transportation use of propane is currently about 2 percent of the propane demand based on data from above and assuming that the transportation use reported in Annual Energy Review 1991, DOE/EIA-0384(91), Table 64, is all propane.

(10) 1992 data, Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Table 3.4.

(11) For 1991. Based on distillate fuel oil for transportation, Annual Energy Review 1991, DOE/EIA-0384(91), Table 64. This category includes off-highway use.

(2) "Chemical Profile—Methanol", Chemical Marketing Reporter, 17 Aug 1992, pp. 50, 17.

(3) Most natural gas used in the U.S. is produced in the U.S. About 12 percent is imported. Nearly all of the imported natural gas is from Canada. A relatively small amount of LNG is imported from elsewhere as LNG. 1992 data, Monthly Energy Review, February 1993, DOE/EIA-0035(93/2)

(14) Propane production calculated using LPG produced, 1992 data, Monthly Energy Review, February 1993, DOE/EIA0035(93/2), Table 3.8 and assumptions used for LPG composition, above.

(15) 1992 data, Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Table 3.4.

(16) Above demand adjusted for imports and exports, 1992 data, Monthly Energy Review, February 1993, DOE/EIA0035193/2), Table 3.5.

(17) Demand in kg, above, times LHV of fuel.

(18) Demand in kg, above, times LHV of fuel.

(19) Demand in kg, above, times LHV of fuel.

(20) Demand in kq, above, times LHV of fuel.

(21) Demand in kg, above, times LHV of fuel.

(22) Demand in kg, above, times LHV of fuel.

(23) Average of three mid-month prices fob U.S. gulf port from Alcohol Week's New Fuels Report for: 21 Oct 92, 19 Nov 92, 16 Dec 92.

(24) Average of three mid-month prices fob Omaha from Alcohol Week'& New Fuels Report for: 12 Oct 92, 16 Nov 92, 21 Dec 92.

(25) Average of natural gas futures prices, next 12 months. Wall Street Journal, 15 Oct 92, 16 Nov 92, 15 Dec 92.

(26) Average of three mid-month propane prices, fob Mont Belvieu, Texas. Reported in Wall Street Journal, 15 Oct 92, 16 Nov 92, 15 Dec 92.

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(28) Price of Number 2 fuel oil, barges New York harbor. Assumes the price of diesel and fuel oil to resellers is the same, which was the case in 1988, cf., Petroleum Marketing Annual 1988 DOE/ EIA-0487(88). Reported in Wall Street Journal, 15 Oct 92, 16 Nov 92, 15 Dec 92.

(29) Includes \$0.04/gal for local terminal and distribution ("Fuel Methanol and Infrastructure for the South Coast Air Basin," Energy and Environmental Analysis, Inc., Arlington, VA, February 1989.) and \$0.06/gal for average shipment from Gulf Coast: cost from Houston to Chicago via barge (Economics of Supplying Methanol as a Transportation Fuel, L.E. Grimes, et al., National Petroleum Refiners Association Meeting, San Francisco, 22 March 1989).

(30) Omaha price plus \$0.07/gal, by analogy with methanol. Will be less in Midwest near production facilities.

(31) Estimated price for firm industrial gas: spot price plus 0.796, which is the difference between the average industrial price, 1992, and gas purchased from producers, 1992, all times 1.131, which is the ratio of firm industrial gas prices, 1991 (latest year available) to all industrial gas, 1991. The 1992 natural gas prices from Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Table 9.11. Firm and interruptible revenues and volumes for 1991 from Gas Fact& 1992, American Gas Association.

(32) Based on Mont Belvieu price plus 0.10 for transportation to Midwest market. Transportation price estimate to local market based on conversations with local propane wholesalers on 9 Oct 90.

(33) Barge price plus 0.098, which is the difference price for resale and price to users. Price data for 1991 from Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Tables 9.6 and 9.7. No taxes are included in price.

(34) Barge price plus 0.033, which is the difference price for resale and price to users. Price data for 1991 from Monthly Energy Review, February 1993, DOE/EIA-0035(93/2), Tables 9.6 and 9.7. No taxes are included in price.

(35) Based on price of methanol at source listed above, volumetric lower heating value energy content, and unit conversions.

(36) Based on price of ethanol at source listed above, volumetric lower heating value energy content, and unit conversions.

(37) Based on price of natural gas at source listed above, volumetric lower heating value energy content, and unit conversions .

(38) Based on price of propane at source listed above, volumetric lower heating value energy content, and unit conversions.

(39) Based on price of gasoline at source listed above, volumetric lower heating value energy content, and unit conversions.

(40) Based on price of diesel fuel at source listed above, volumetric lower heating value energy content, and unit conversions .

(41) Based on delivered price of methanol listed above, volumetric lower heating value energy content, and unit conversions .

(42) Based on delivered price of ethanol listed above, volumetric lower heating value energy content, and unit conversions.

(43) Based on delivered price of natural gas listed above, volumetric lower heating value energy content, and unit conversions.

(44) Based on delivered price of propane listed above, volumetric lower heating value energy content, and unit conversions.

(45) Based on delivered price of gasoline listed above, volumetric lower heating value energy content, and unit conversions.

(46) Based on delivered price of diesel fuel listed above, volumetric lower heating value energy content, and unit conversions.

(47) Delivered cost including CNG compression cost estimate of $.90//GJ equivalent prepared by Reuinald Webb for a presentation on "The Economics of Using Gaseous Fuels in Buses," and contained in the proceedings of the Third Windsor Workshop on Alternative Fuels, 24-26 June 1987. p. 216. (Inflation assumed to be 25.6 percent usinU Implicit GNP Price Deflator for fourth quarter 1992).

(48) Delivered cost includinu cost of liquefaction based on cost analysis of G.A. Constable, C. John Gibson and Anker Gram in "Use of LNG in Heavy-Duty Vehicles," SAE paper 891670, 1989. Analysis is for LNG system with 18,500 liters/day diesel equivalent capacity. (Inflation assumed to be 15.7 percent using Implicit GNP Price Deflator for fourth quarter 1992).