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TCRP Synthesis 1

Safe Operating Procedures for Alternative Fuel Buses

A Synthesis of Transit Practice

Transportation Research Board
National Research Council

TRANSIT COOPERATIVE RESEARCH PROGRAM

Synthesis of Transit Practice 1

Safe Operating Procedures for Alternative Fuel Buses

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TRANSIT COOPERATIVE RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on many subjects of concern to the transit industry. This information has resulted from research and from the successful application of solutions to problems by individuals or organizations. There is a continuing need to provide a systematic means for compiling this information and making it available to the entire transit community in a usable format. The Transit Cooperative Research Program includes a synthesis series designed to search for and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in subject areas of concern to the transit industry.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on measures found to be successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff Transportation Research Board

This synthesis will be of interest to transit agency managers, maintenance managers, and other personnel concerned with the operation of bus fleets using alternative fuels to meet national and local requirements related to air quality and energy diversification. Information on the use of methanol, ethanol, compressed natural gas (CNG), liquified petroleum gas (LPG), liquified natural gas (LNG), and other alternatives is included.

Administrators, engineers, and researchers are continually faced with problems on which there is much information, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and or not readily available in the literature, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to the available methods of solving or alleviating the problem. In an effort to correct this situation, the Transit Cooperative Research Program (TCRP) Synthesis Project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common transit problems and synthesizing available information. The synthesis reports from this endeavor constitute a TCRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to a specific problem or closely related problems.

Many aspects of handling and use of alternative fuels differ from conventional diesel and gasoline fuel used by transit agencies and are not yet covered by regulations, standards, or generally accepted practice. While many agencies have only limited experience with prototype alternative fuel buses, others have demonstrated effective techniques and practices for safe operation of both the buses and the refueling and maintenance facilities. This report of the Transportation Research Board describes the
characteristics of various alternative fuels in use by transit agencies and discusses several aspects of these fuels and

handling practices including training procedures, fuel storage and handling, maintenance operations considerations, facility requirements, issues related to the buses, facility and operating costs, and environmental considerations.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, available information was assembled from numerous sources, including a large number of public transportation agencies. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now on hand.

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The Principal Investigators responsible for the conduct of the synthesis were Sally D. Liff, Manager, Synthesis Studies, and Donna L. Vlasak, Senior Program Officer. This synthesis was edited by Linda S. Mason.

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SAFE OPERATING PROCEDURES FOR ALTERNATIVE FUEL BUSES

SUMMARY

Alternative fuels are used by transit agencies across the United States, and will become part of the operations of many more transit agencies in coming years. Driven by considerations such as air quality and energy diversification, various mandates and incentives have been created that will lead to the use of alternative fuels for transit applications. The Clean Air Act Amendments of 1990, for example, provide for aggressive improvement in transit bus emissions beginning in 1994. Many state and local agencies (such as the California Air Resources Board and the Northeast States for Coordinated Air Use Management) are enacting or considering various measures that will either require or provide incentives for the use of alternative fuels in vehicles, including transit buses.

Unlike conventional diesel and gasoline fuel, some aspects of alternative fuel handling and use are not yet covered by regulations, standards, or even accepted practice. While alternative fuels such as compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gases (LPG), methanol, and ethanol have been demonstrated at the prototype level at several transit locations nationwide in recent years, most transit operators remain unfamiliar with the specific techniques and practices needed for safe vehicle operation, maintenance, and refueling. Other alternative fuels and propulsion systems, such as biodiesel, electricity, and solar power, have been tested or placed in operation only on a limited basis and are not covered in this synthesis. Education and training of transit managers and operations staff are vital to ensure that the appropriate practices are identified, understood, adopted, and executed. This synthesis is basically a primer to provide transit operators with information on alternative fuels and on how transit agencies with experience in their use have addressed the advantages and disadvantages of these fuels and the necessary changes in storage, handling, operating, and fueling procedures.

This synthesis addresses the following aspects of alternative fuels and handling practices by transit agencies in the United States:

- Training procedures,
- Fuel storage and handling,
- Maintenance operations considerations,
- Facility requirements,
- Vehicle related issues,
- Cost (facility and operating), and
- Environmental considerations.

Current codes and standards do not filly cover all aspects of alternative fuel use, although consideration has been given to certain fuels in some arenas. For example, the National Fire Protection Association (NFPA) has developed codes for CNG, LNG, and LPG fuel storage and dispensing, but these requirements do not specifically apply to maintenance facilities unless the refueling and maintenance occur in the same area. Where current regulations and codes do not provide guidance, engineering judgement and use of codes for comparable fuels must be applied to such issues as fuel leaks, flammability, flame luminosity, toxicity, and other potential concerns. This synthesis discusses aspects of alternative fuel use in transit that are not covered by traditional codes and standards, and provides examples of the engineering considerations for situations not covered by traditional codes and standards, and provides examples of the engineering consideration for situations not covered by existing code. One additional complication is that standardization of requirements is not adequate. Local fire prevention officials often have jurisdictions and final approval authority over refueling facilities, for example, and the requirements imposed by such local authorities in the absence of NFPA or other guidelines may differ substantially from one locale to another. This makes planning and engineering difficult for each transit agency considering alternative fuels.

Current practice of transit agencies using alternative fuels either in a demostration or as a long-term move into a new fuel is described based on data supplied by 17 transit agencies through a combination of mailed questionnaire/surveys and site visits. As expected, various transit agencies respond somewhat differently to the set of actual regulations, local requirements, and best-judgement approaches. Nevertheless, probably because methanol, LPG, and CNG have become well-known alternative fuels for transit, fuel handing and operation modifications for these fuels seem to be most consistent among the sites surveyed. Only one site provided information about its handing of LNG fuel, a newcomer to the transit arena, so the discussion of current practice for this fuel relies almost exclusively on the experiences of that single agency. Information from only one user of ethanol is included in this study. However, this agency is a representative example of future mainstream ethanol use with factory-built, emissions-certified dedicated ethanol engines, as opposed to converted dual-fuel ethanol/diesel engines in use at some other sites. Because of the fuels' similarity, much of the methanol experience can be direclty applied to ethanol.

Several trends surfaced from the information provided. For methanol and ethanol, most agencies did not undertake major facility modifications aside from refueling facility installation. Many respondents employed fire protection systems on-board the methanol buses, and occasionally in service facilities. Operational constraints most often mentioned with methanol buses were reduced driving range, special refueling and maintenance procedures (most agencies performed refueling on-site), and increased downtime of buses. Most respondents took advantage of training sessions and materials provided to them by fuel suppliers or other sources.

Some CNG users made modifications to maintenance facilities, such as increasing ventilation and upgrading electrical equipment, although several CNG respondents made no special facility changes. Among the operational constraints named were slow refueling, reduced acceleration power, reduced range and payload, and increased downtime. CNG users reported that training sessions and materials were generally provided by fuel suppliers or other sources.

LPG respondents reported no modifications to facilities other than addition to refueling capability. Reduced range, new refueling procedures, and increased downtime were listed as operational constraints. Traininig sessions and materials were provided by fuel suppliers and consultants.

The LNG respondent initially made no facility modifications, but has since instituted some changes to ventilation and heating systems in maintenance buildings. More frequent refueling was noted as an operational constraint of LNG use (in pilot-ignited diesel engines), and the agency has three refueling bases in its operating region. The agency has developed a four-part training course for mechanics, and LNG bus operators participate in a 4-hour classroom training session.

The data gathered in the process of compiling this synthesis indicate several conclusions. The technical and safety issues associated with the use of methanol and ethanol in transit are well understood and, for the most part, resolved. The cost of these fuels, however, is substantially higher than diesel on an energy-equivalent basis, which translates into higher operating costs for transit agencies that choose methanol or ethanol. For CNG, the low fuel density (about 5 to 1 compared to gasoline) translates into range and payload penalties, although recent developments in lower weight storage cylinders can reduce this disadvantage. The engine and fuel system technology for CNG is approaching acceptable levels of performance and reliability, and the operating cost of CNG fuel is similar to that of diesel. CNG is regarded as a safe fuel to handle and operate however, a methane detector is generally needed to detect leaks. For LNG, the technical issues of handling cryogenic liquids are less familiar to transit operators, and operating experience with LNG buses is contributing to the available knowledge about safety concerns as well as operational issues. LNG requires some special safety provisions, such as methane detectors, to sense the presence of any leaks into enclosed areas. For LPG, the technical issues of its use in transit are mostly resolved; engine and fuel system reliability are approaching desired levels of performance and reliability. Under current market conditions, the cost of LPG operation is similar to diesel. The safety concerns and handling requirements of LPG fuel are well understood.

The five alternative fuels studied in this synthesis report are all potentially viable options that would allow transit agencies to meet the provisions of the Clean Air Act. Many agencies will also consider the option of continuing to use diesel fuel and purchase new diesel buses. Diesel engine manufacturers appear to be confident that they can manufacture engines that will meet exhaust emission requirements in coming years. However, the emissions performance of alternative fuels may induce the Environmental Protection Agency and the California Air Resources Board to promulgate even more stringent requirements for transit buses, putting the long-term future of diesel-powered buses in nonattainment areas in some doubt. Biodiesel, fuel-cell, and battery-powered buses are possible future options to be considered, but these technologies do not currently appear ready for the market. Table S-1 summarizes alternative fuels properties and practices.

TABLE S-1
SUMMARY OF ALTERNATIVE FUEL PROPERTIES AND PRACTICES

	Methanol	Ethanol	CNG	LPG	LNG
Storage	As for conventional fuels	As for conventional fuels	High pressure cylinders (up to 5,000 psi)	Moderate pressure tanks (up to 375 psi)	Cryogenic (-26°F) moderate pressure (up to 150 psi)
Dispensing	As for conventional fuels; positive locking nozzle desirable	As for conventional fuels; positive locking nozzle desirable	Specialized high-pressure fueling connector	Specialized fueling connector	Specialized cryogenic fueling connector
Vapor Recovery	Desirable	Desirable	Not applicable	Desirable	Required
Exposure Hazards	Highly toxic via ingestion, vapor inhalation, or skin contact	Moderately toxic via ingestion	Physical hazard due to high pressure, can cause injury or embolism	Physical hazard due to pressure, can cause injury or embolism; latent heat of vaporization can freeze tissue	Serious physical hazard due to cryogenic temperature; contact with fuel or equipment cooled by fuel can cause severe frostbite
Fire Hazards	Vapor heavier than air; flame invisible in daylight; ignites more readily than diesel	Vapor heavier than air; flame nearly invisible in daylight; ignites more readily than diesel	Released gas is lighter than air; ignites more readily than diesel	Vapor heavier than air; ignites more readily than diesel	Vapor lighter than air; ignites more readily than diesel
Fire Prevention for Facilities	Ventilation and/or explosion-proof equipment at floor level and in pits	Ventilation and/or explosion-proof equipment at floor level and in pits	Ventilation and/or explosion-proof equipment at ceiling level and in pits	Ventilation and/or explosion-proof equipment at floor level and in pits	Ventilation and/or explosion-proof equipment at ceiling level and in pits; methane detectors desirable as fuel is not odorized
Automatic On-Board Fire Suppression	Desirable	Desirable	Desirable	Desirable	Desirable
Capital Costs	Moderately higher than diesel	Moderately higher than diesel	Significantly higher than diesel	Moderately higher than diesel	Significantly higher than diesel
Operating Costs	Significantly higher than diesel	Significantly higher than diesel	Similar to diesel	Similar to diesel	Similar to diesel
Vehicle Issues	Moderate range and/or weight penalty	Slight-to-moderate range and/or weight penalty	Significant range and/or weight penalty	Slight range and/or weight penalty	Slight range and/or weight penalty

CHAPTER ONE

INTRODUCTION

BACKGROUND

Alternative fuels will soon becomes a fact of life for many transit agencies in the United States. It is generally held that alternative fuels can help improve air quality in polluted metropolitan areas, and legislators and regulators have translated these research findings into mandates for many fleet operators, particularly transit agencies, to introduce alternative fuels buses into their fleets. For example, the Clear Air Act Amendments (CAAA) of 1990 require significant reduction of pollutants from various sources, including transmit service agencies, and alternative fuels offer one means of achieving these reductions. Unlike conventional diesel and gasoline fuel, some aspects of alternative fuels handing and use are not yet covered by regulations, standards, or even accepted practice. While alternative fuels such as compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gases (LPG), methanol, and ethanol have been demonstrated at the prototype level at several transit locations nationwide in recent years, most transit operators remain unfamiliar with the specific techniques and practices needed for safe vehicle operation, maintenance, and refueling. Appropriate management attention to the need for the safe handling of alternative fuels is essential. This synthesis is essentially a primer to provide information to general managers, maintenance managers, and others who may be looking at safe operation with alternative fuels for their bus fleets. It should be noted that this synthesis describes U.S. experience and conditions only; Canada and other countries have also had extensive experience with these fuels.

Properties of Conventional and Alternative Fuels and Their Implications

The alternative fuels studies in this synthesis have properties different from and some more hazardous than those of the conventional fuels used by transit agencies. The Federal Transit Administration (FTA) has recently called attention to some of the differences in a letter to all transit agencies (see Appendix A). Some of the alternative fuel property differences that all users and potential users need to be aware of are highlighted below and summarized in Table S-1.

Considerations for Fuels with Heavier-than-Air Vapors

Gasoline, diesel, methanol, ethanol, and LPG vapors tend to accumulate at ground level, or in low-lying regions such as maintenance pits. Because of their high vapor pressures at room temperature, gasoline, methanol, ethanol, and LPG pose a significant fire hazard. As a result, the use of these fuels in areas with pits requires adherence to stringent electrical classifications, e.g., explosion-proof equipment in the pits and areas below 18 in. above grade level. Electrical classification requirements are based on the composition and gas, and the likelihood of the gas being present. This links the electrical classification to the building ventilation rates; if the ventilation disperses the gas quickly, the likelihood of a flammable concentration accumulating is decreased.

Considerations for Lighter-than-Air Gaseous Fuels

Unlike gasoline, methanol, ethanol, and LPG, natural gas is lighter than air and natural gas vapors near room temperature will rise and accumulate at ceiling level in enclosed areas. Thus the situation for natural gas is similar to heavier-than-air fuels, but inverted. Stringent electrical classification, e.g., explosion-proof equipment, are advised in ceiling areas and areas in which lighter-than-air gas can be trapped. Ventilation can also be used to prevent the accumulation of hazardous concentrations of natural gas in areas where it might otherwise accumulate.

Other Important Safety Considerations for Alternative Fuels

The extremely low temperature of LNG (-260º F) makes special handling and equipment necessary. Because it is not odorized like other forms of natural gas, leaks cannot be detected by smell. Current LNG fueling equipment does not assure leak-free connections, and the very low temperature presents a cryogenic burn hazard to personnel (see FTA letter, Appendix A).

Methanol is toxic to humans when ingested, inhaled, or in contact with the skin for a prolonged period. Ethanol is toxic mainly through ingestion, though less harmful for a given dose than methanol. Education and training are needed to ensure that personnel do not come to harm from these fuels (see FTA letter, Appendix A). Through the Transportation Safety Institute (TSI), FTA offers an instruction course on alternative fuels safety and a seminar titled "Emergency Response and Access to Alternative Fueled Vehicles," at several locations in the United States. Information can be obtained from TSI at (405) 954-3682.

REQUIREMENTS OF THE CLEAN AIR ACT AMENDMENTS (CAAA) OF 1990 AND OTHER FEDERAL AND STATE LEGISLATION

This section summarizes the provisions of the CAAA of 1990 and other federal and state legislative policies and enactments as they apply to transit vehicles and operations. It also discusses relevant requirements and activities that must be undertaken by transit operators to bring systems into compliance with these regulations. Federal requirements, as well as the state regulations for California, Colorado, and Texas are described in this section. Eighteen states currently mandate the use of alternative fuels for fleet vehicles under certain circumstnaces.

Section 119(c) of the CAAA [42 U.S.C. 7554(c)] requires the U.S. Environmental Protection Agency (EPA) administrator to conduct tests of the particulate emissions from 1994 and later model-year urban buses to determine whether diesel buses comply with the particulate standard for the full useful life (290,000 miles) of the vehicles. If the administrator determines that the diesel buses do not comply, then regulations must be developed requiring the phase-in or purchases of new buses that operate on low-polluting fuels. The phase-in of such a requirement covers 5 model years beginning 3 years after the determination that diesel buses do not comply with the full useful life requirement. Thus, if diesel fuel technology fails to meet the 0.07-grams per brake horsepower-hr (g/bhp-hr) standard that applies in 1994 or the 0.05 g/bhp-hr standard that applies in 1996 in actual use, the CAAA states that

> The administrator shall promulgate a schedule phasing in any low-polluting fuel requirement established pursuant to this paragraph to an increasing percentage of new urban buses purchased or placed into service in each of the first five model years commencing three years after the determination under subparagraph (A). Under such schedule 100 percent of new urban buses placed into service after the determination under subparagraph (A) shall comply with the low-polluting fuel requirement established pursuant to this paragraph.

This could mean that all new urban buses purchased by transit agencies would have to be alternative fuel buses after the early 2000s. Possible fuels include natural gas (both CNG and LNG), propane, methanol, and ethanol.

The California Air Resources Board (CARB) has considered several proposals for new low-emissions standards for heavy-duty engines in general and for urban bus engines in particular. The current proposal for urban bus engines to be effective in 1996 is 4.0 g/bhp-hr for oxides of nitrogen (NO_x) and 0.05 g/bhp-hr for particulates. Even lower standards are proposed for the early 2000s. Diesel technologies may not be able to meet the combined NO_x/particulars standard (at least not in-use), so that if these standards prevail, they may force new buses purchased in California to be alternative fueled. In California, the South Coast Air Quality Management District (SCAQMD) and the Sacramento Metropolitan Air Quality Management District (SMAQMD) are developing “fleet rules” that requires certain fleets (including transit bus fleets) to purchase “low-emissions” heavy-duty vehicles when vehicles are being added or replaced. For this purpose, the air quality districts can use an existing statutory definition of a “low-emissions heavy-duty vehicle” as one that meets one-half of the then-current NO_x of particulate standard (California Health and Safety Code Section 43800(d)). A fleet rule written to require this NO_x reduction would effectively force the purchase of non-diesel buses. The Sacremento Regional Transit District (SRTD) has recently committed to the purchase of 95 new CNG buses powered by Cummins L-10 engines which will be certified at 50 percent below the current 5 g/bhp-hr NO_x standard in anticipation of a fleet rule being adopted in Sacramento. The board of the Los Angeles County Metropolitan Transit Authority (LACMTA) has made a policy decision for the use of alternative fuels in their operations by purchasing only alternative fuel buses in the future, a move that is expected to reduce NO_x emissions in the region by about 1 percent (*LA Times*, Oct. 28, 1993 “MTA Votes to Stop Buying Buses That Burn Diesel Fuel”). The municipality of Metropolitan Seattle (Seattle Metro) has made a similar commitment, choosing to convert their bus fleet to LNG in a 1993 policy decision.

Some state and local governments have instituted specific clean-fuel or alternative fuel mandates that apply to urban buses and other fleets. Some of these programs, such as those in Texas, can have a decisive influence on fuel choice. Section 114.11 of the Texas Regulation IV of the Texas Natural Resource Conservation Commission, Control of Air Pollution from Motor Vehicles (relating to alternative fuel requirements for transit authorities) specifically provides that in air quality non-attainment areas with populations of more than 350,000, fleet vehicles must be capable of operating on alternative fuels such as natural gas, liquefied petroleum gas, electricity, methanol or methanol/gasoline blends of 85 percent (M85) or greater, or ethanol or ethanol/gasoline blends of 85 percent (E85) or greater. This regulation also provides that capability for operating on alternative fuels shall be accomplished in accordance with the following schedule: (a) 30 percent or more or fleet vehicles by September 1, 1994; and (b) 50 percent or more of fleet vehicles by September 1, 1996. These compliance requirements may be met by vehicles that are dedicated solely to the use of an alternative fuel or are capable of being operated on an alternative fuel and gasoline, diesel, or other conventional fuel, separately or in combination *(1)*. This Texas legislation induced the Metropolitan Authority of Harris County (Houston Metro) to begin conversion of their bus fleet to LNG in 1990. The State of Oklahoma Alternative Fuels Conversion Act encourages that school buses and government vehicles be converted to operate on an alternative fuel. This Act further provides that beginning July 1, 1995, all school districts within the state should consider purchasing only school buses and multi-passenger vehicles that can operate on an alternative fuel such as compressed natural gas, liquefied petroleum gas, liquefied natural gas, ethanol, or electricity *(2)*. The state of Colorado has developed a regulation that implements economic incentives for vehicle owners to convert their vehicles to the use of alternative fuels or purchase new alternative fuel vehicles. This regulation also enacts certification standards and procedures for alternative fuel vehicle retrofit kits, certified by vehicle type (automobile, truck, or bus), which will fulfill applicable EPA regulations *(3)*.

The National Energy Policy Act of 1992 (EPACT) *(4)* includes several provisions affecting urban buses. Although buses are not included in the requirements for local government and private fleets to acquire alternative fuel vehicles, Section 507(k) in Title V directs the Secretary of Energy to determine whether the inclusion of new urban buses would contribute to the quantified goals of energy diversification. If so, and if other conditions are met, then some fraction of new urban buses will need to be alternative fuel buses to meet local fleet purchase requirements.

PURPOSE AND METHODOLOGY

The purpose of this synthesis is to provide information to transit operators on how transit agencies in the United States with some experience in alternative fuels use have addressed the advantages and disadvantages of these fuels and the necessary changes in storage, handling, operating, and fueling procedures that are required for safe operation.

This document provides information on the practices used to store, transport, and handle alternative fuels, including LNG, LPG, CNG, ethanol, and methanol and discusses the benefits and effectiveness of these practices. The synthesis addresses the following specific aspects of alternative fuels and handling practices:

- Training procedures,
- Fuel storage and handling,
- Maintenance operations considerations,
- Facility requirements,
- Vehicle related issues,
- Cost (facility and operating), and
- Environmental considerations.

The sources of information for this synthesis include a review of publicly available literature on transit experience with alternative fuels (including the Transportation Research Board (TRB) Transportation Research Information System (TRIS)), a questionnaire mailed to a selection of U.S. transit agencies known to have experience with alternative fuels, and extensive reviews of practices employed by five transit agencies that operate alternative fuel buses.

CHAPTER TWO
PUBLISHED INFORMATION

The legislative requirements for transit fleets regarding alternative fuels require transit agencies to examine the impacts on existing facilities and procedures when implementing an alternative fuel program.

In order to examine general guidelines, standards, and practices regarding the implementation of alternative fuels in transit agencies, a literature search and code review was conducted. Because of the relatively recent emergence of alternative fuel use, codes and standards for many areas have not been formulated. Numerous demonstration projects and studies have been conducted to ascertain the impacts on facilities and operating procedures with the emergence of alternative fuels. The relevant papers, studies, and experiences related to alternative fuel use were examined and are listed in the Bibliography. Fueling and maintenance facility modifications, as well as potential changes to operating procedures, must be addressed when implementing alternative fuels in transit applications. The following sections present the results of the literature search and the areas addressed by codes and standards with respect to alternative fuel use.

Literature Review

Three primary resources provided information: the consultant's own literature database, Transportation Research Board (TRB) Transportation Research Information System (TRIS), and Stanford University's Online catalog system (EI Compendex). The literature search revealed 36 documents, which appear in the Bibliography.

Additional information is found in the National Fire Protection Association standards (NFPA), Occupational Safety and Health Administration (OSHA) codes, and various state and local codes.

Code Review (*5*)

In many cases, the most thorough guidelines for the requirements of implementing alternative fuels in transit agencies are found in the NFPA codes and standards. Table 1 lists the NFPA codes relevant to storage, use, and dispensing of flammable liquids, compressed gases, and liquefied gases. Each of the alternative fuels covered here falls into one of the above categories. NFPA 325M indicates that methanol and ethanol, like gasoline, are classified as Class I-B flammable liquids. (The flash points of these liquids are below 73°F {23°C} and the boiling points are above 100°F{38°C}). The *health, flammability, reactivity* ratings of methanol, ethanol, and gasoline found in NFPA 321 are the same at 1, 3, 0. A "0" denotes no hazard and a "4" the greatest hazard in each category. Therefore, the requirements for gasoline servicing and fueling facilities hold for methanol and ethanol. Diesel fuel, on the other hand, is a Class II combustible liquid. The requirements for servicing and fueling areas in which diesel fueled vehicles are serviced are less stringent than those for gasoline, methanol, and ethanol. Implementation of methanol or ethanol use in a facility designed for gasoline use requires minimal renovation. If, as is common for transit, the existing facility is built to meet codes required for diesel use, significant upgrades may be required. Although NFPA presents clear guidelines for storage, use, and dispensing of alternative fuels, the NFPA codes frequently do not address the requirements for facilities in which maintenance and repair of transit buses are completed. Ultimate authority for approval or disapproval of implementing an alternative fuel rests with the local authority having jurisdiction, usually the fire prevention official, who may or may not hold the guidelines published by NFPA and others to be of value. Transit agencies using alternative fuels have learned from their experience the paramount importance of consulting with the local authorities at the earliest stages in their plans to use alternative fuels.

Other sources of published information containing guidance on equipment and facility safe design practices are the Petroleum Equipment Institute (PEI), American Petroleum Institute (API), Underwriters Laboratories (UL), and American Society for Testing and Materials (ASTM).

CNG, LNG, and LPG each has specific NFPA codes defining the requirements related to these fuels, including storage and dispensing locations, area electrical classification, operating procedures, ventilation requirements, and storage tank requirements. Specific NFPA standards are not written for methanol and ethanol, so standards 30 and 30A are used. As mentioned above, these codes typically address fueling facility, storage, and handling requirements. Maintenance facility requirements are not covered unless the fueling occurs within the maintenance area.

Gasoline, diesel, methanol, ethanol, and LPG vapors, if accidentally released, tend to accumulate at ground level, or in low-lying regions such as maintenance pits. As a result, the use of these fuels in areas with pits requires stringent electrical classifications, i.e. explosion-proof equipment in the pits and below 18 in. (0.46 meters) above grade level. Electrical classification requirements are based on the composition of gas, and the likelihood of the gas being present. This links the electrical classification to the building ventilation rates: if the ventilation disperses the gas quickly, the likelihood of a flammable concentration accumulating is decreased. Unlike gasoline, methanol, ethanol, and LPG, natural gas is lighter than air and natural gas vapors near room temperature will rise and accumulate at ceiling level in enclosed areas. The NFPA codes do not specifically identify electrical classification requirements for indoor maintenance areas where CNG or LNG vehicles are serviced. Ventilation at ceiling level can be employed to ensure that no areas exist in which flammable pockets of gas might accumulate.

The NFPA codes present minimum ventilation rates required to prevent flammable vapor accumulation in fueling facilities. The ventilation rates are directly related to the electrical classification requirements. Operators of maintenance facilities requiring electrical system upgrades may elect to increase the ventilation rates and

TABLE 1
SOME RELEVANT NATIONAL STANDARDS AND CODES FOR ALTERNATIVE FUEL IMPLEMENTATION

NFPA 30	Flammable and Combustible Liquids Code
NFPA 30A	Automotive and Marine Service Station Code
NFPA 52	Standard for Compressed Natural Gas Vehicular Fuel Systems
NFPA 58	Standard for Storage and Handling of Liquefied Petroleum Gases
NFPA *59A*	Standard for Production, Storage, and Handling of Liquefied Natural Gas (LNG)
[NFPA 57]	Standard for Liquefied Natural Gas Vehicular Fuel Systems [NFPA 57 is currently in draft form and is expected to be published in 1994.]
NFPA 70	National Electrical Code
NFPA 88B	Standard for Repair Garages
NFPA 90A	Standard for the Installation of Air Conditioning and Ventilating Systems
NFPA 91	Standard for Exhaust Systems for Air Conveying of Materials
NFPA 101	Code for Safety to Life from Fire in Buildings and Structures
NFPA 321	Standard on Basic Classification of Flammable Liquids, Gases and Volatile Solids
NFPA 325M	Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment
NFPA 497M	Manual for Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations
UFC	Uniform Fire Code
UBC	Uniform Building Code
UPC	Uniform Plumbing Code
UMC	Uniform Mechanical Code
CFR	Code of Federal Regulations

avoid the cost of replacing the electrical system. For systems with indoor fuel dispensing, this option is not available.

Another area in which guidelines are not spelled out in the codes regards potential release of (alcohol) alternative fuels into the sewer or drainage system. The release of flammable liquids into the sewer systems is prohibited by NFPA 30 Section V-3.4. Means must be provided to prevent entry of flammable liquids into the sewer. Where fuel is handled and an emergency drain connects to a sewer, separators or clarifiers are required for gasoline, diesel, or oil spills. Methanol and ethanol, however, are soluble in water and will pass through the separator. Means of separating methanol or ethanol from water exist, although, the processes are troublesome and costly. One example is an activated carbon filter. This filter would need periodic checking, and can treat only a limited quantity of waste stream. The saturated filter presents a new hazardous material disposal problem. The best approach may be to ensure that spills of these fuels are absolutely prevented from entering the drains through which they may potentially enter the sewer system.

The modification requirements for each alternative fuel are primarily based on the chemical and physical characteristics of that fuel. Flammable vapor behavior drives the electrical classification and ventilation requirements. Solubility issues need to be addressed with respect to potential drainage problems. In addition, CNG is stored at high pressure, therefore presenting a potential hazard for high-pressure release. LNG is cryogenically stored and must be handled with special precautions. Regardless of the alternative fuel choice, modifications to the facilities and standard operating procedures will be required.

Published information is available to inform many aspects of a transit agency's transition to the use of alternative fuels. However, some significant gaps in safety codes and standards have been pointed out here and are emphasized by the experiences of transit agencies already using alternative fuels. In any event, it is most important to consult with the local fire prevention and emergency medical services (EMS) officials for guidance.

CHAPTER THREE

AN OVERVIEW OF ALTERNATIVE FUELS FOR BUSES

The five alternative fuel choices considered in this synthesis, methanol, ethanol, CNG, LPG, and LNG, are being evaluated by one or more U.S. transit agencies as fuels to replace diesel or gasoline. In this chapter, safety and maintenance practices used by these agencies are discussed for training procedures, fuel storage and handling, maintenance operations considerations, facility requirements, vehicle related issues, cost (facility and operating), and environmental considerations.

Evaluation of these activities was based on a review of the literature and on experience gained from numerous alternative fuel engine development and vehicle demonstration projects *(6,7,8)*. This section presents a type of primer on these fuels and is not intended to be all-inclusive.

METHANOL

Methanol is a pure organic substance, i.e., a hydrocarbon of fixed composition. By comparison, gasoline and diesel fuel are petroleum products consisting of many different types of hydrocarbon molecules, with no standard or average composition. The physical and chemical properties of methanol, like any pure substance, are invariant. Physical and chemical properties of diesel and gasoline, on the other hand, can vary with composition, though they are held within a desirable range by controlling refinery basestock and processes.

Methanol was the alternative fuel that first received attention and serious funding from state agencies and engine manufacturers. The results of several demonstrations have been documented in a number of interim and final reports *(6, 7,8,9,10,11,12)*

Training

Because its properties make it different from gasoline and diesel in terms of fire safety, operating and safety training is required for personnel who operate and maintain methanol fueled vehicles. Transit agencies that use methanol fuel provide training to address the safety requirements for methanol, often using a training manual developed by the Federal Transit Administration (FTA) *(13)*. The FTA manual and training programs such as the TSI program cover the safety topics discussed in the Safety subsection. Operators are also trained in the special aspects of methanol bus operations, including engine starting and warmup characteristics and emergency procedures.

Storage and Handling

Methanol fueling facilities consist of a storage tank and dispenser that can be integrated with the existing diesel fueling facility. Existing steel storage tanks can be retrofitted for methanol use. Newer alcohol-compatible fiberglass tanks can also be used for methanol storage *(14)*. Fuel dispensing equipment usually consists of new methanol-compatible pumps and dispensers. Methanol dispensers are usually equipped with mechanically locking nozzle systems that deliver fuel at about 40 gallons per minute (150 liters per minute). The nozzles can be configured to connect only with the methanol bus' fuel tank, to prevent inadvertent fueling of a nonmethanol bus with methanol, or vice-versa. At California transit agencies, methanol fueling facilities are equipped with vapor recovery systems. Vapor recovery is accomplished with a vapor return hose that is connected to a vapor return fitting on the vehicle fuel tank during fueling operations.

Maintenance Operations Considerations

Methanol vehicles require some of the same routine maintenance operations as conventionally fueled vehicles. Most of the engine components of the DDC 6V-92TA methanol engine are the same as those for the diesel engine. Glow plugs, unique to the methanol engine, require occasional replacement; however, the rate of glow plug replacements has been reduced as DDC has configured the engine to use glow plugs only for starting and low-load operation.

Methanol bus fuel systems also require special attention. Fuel filters must be replaced on a regular basis or they become plugged and reduce the flow of fuel to the engine.

Facility Requirements

Facility requirements include fueling and maintenance facilities. For methanol operation, requirements for these facilities are similar to those for diesel fuel.

Maintenance facility requirements are functionally similar to those for diesel fuel. Methanol buses require basically the same tools and equipment for maintenance as diesel buses. Methanol engines require a special engine oil formulation. Agencies with a small number of methanol buses typically purchase and stock this oil in drums. Some agencies with large methanol fleets are installing additional reel-mounted engine oil dispensers for bulk oil purchase and dispensing.

NFPA requirements for methanol are similar to those for gasoline. Fueling facilities must have a Class 1 Division 1 area classification. Most fueling facilities already meet this requirement and do not need modifications for methanol. Maintenance garages are required to meet either a Class 1 Division 2 area classification or have sufficiently high ventilation rates in the underground pits and maintenance area. Some newer maintenance facilities already meet these requirements and therefore are suitable for methanol bus maintenance. Other transit operators with older facilities limit indoor maintenance on methanol buses by performing maintenance outdoors and using moveable lifts. Some efforts are underway to upgrade older maintenance facilities.

Vehicle Related Issues

Issues related to transit vehicle characteristics that are often considered for methanol transit bus operation include performance and acceleration, vehicle range, vehicle weight limits, compatibility of fuel system materials with methanol, and travel through tunnels.

Most methanol engines in service in the United States are the DDC 6V-92TA. The electronically controlled version of the engine uses glow plugs to assist with cold starting and modulation of the air supply to the engine, combined with an increased compression ratio, allows the engine to compression ignite methanol. Some older buses have been retrofitted to operate on methanol with an ignition enhancer. M100 or 100 percent methanol is typically used for these engines. Gasoline is not added in this fuel formulation, however, the methanol engine does require an additive to prevent injector tip plugging.

The performance of methanol engines is similar to that of comparable diesel engines. Methanol bus engines are similar to diesel engines in that fuel is directly injected into the combustion chamber and compression ignited. Engine power depends partly on fuel injector capacity. Secondary factors include injection timing and air flow to the engine. Differences in acceleration performance between methanol and diesel engines depend on the engine configuration and horsepower rating. As is the case with diesel engines, methanol engines with plugged injectors experience a loss in acceleration performance.

Manufacturers of methanol fueled engines and buses are careful to select methanol-compatible materials for the fuel system. Stainless steel is the material of choice for fuel tanks and fittings, while stainless steel braid reinforced teflon tubing is used for flexible fuel lines.

The range of methanol buses depends on the fuel economy and fuel storage capacity. A methanol bus requires about 2.3 to 2.6 times as much fuel to go the same distance as a similar diesel bus. The diesel buses are often not identical in terms of configuration or emissions and the comparison of fuel economy varies at different transit agencies. Because larger tanks are used on methanol buses than on equivalent diesel buses, some of the range penalty resulting from the lower volumetric energy content of methanol is offset. Available operating range for methanol buses is typically 250 to 350 miles (400 to 560 kilometers); the range for diesel buses is about 150 miles (240 kilometers) higher. The range for methanol buses allows them to operate on most transit routes. Refueling time for methanol buses is not an issue when rapid-fill fueling nozzles are used. With a flow rate of 50 gallons per minute (180 liters per minute), and an empty tank refill capacity of approximately 270 gallons (1000 liters), a bus that is not empty can be fueled in less than five minutes.

The curb weight for a typical full-size methanol bus is about 1,100 lb (500 kg) higher than that of a comparable diesel bus. To agencies having difficulty with full passenger loads and rear axle weight limits, this additional weight may be significant. In one agency's experience, rear axle weight of otherwise identical diesel and methanol buses is considered legal for 60 and 52 passengers respectively.

Operating methanol buses in tunnels was considered an issue in New York City because of an interpretation of rules governing the transport of hazardous materials. Methanol in the fuel tank was considered a hazardous material. A study for the Triborough Bridge and Tunnel Authority *(15)* assessed the relative safety of methanol, diesel, and gasoline bus operation in tunnels. The study found that the fire hazard with a methanol bus was not significantly higher than with conventionally fueled buses. The local agencies subsequently allowed the operation of methanol buses in tunnels.

Safety

Methanol differs from gasoline and diesel in its fire hazards. Like gasoline and diesel, methanol is also toxic on ingestion. Relatively small doses of methanol can result in toxic effects in a few hours *(16).*

Fire Hazards

Methanol spills are more likely to ignite than diesel spills and methanol burns with an invisible flame in daylight. Smoking should be prohibited when fueling methanol vehicles and during many maintenance activities.

Fire fighting requirements need to be considered for methanol. Alcohol-resistant foams are required for fighting large methanol fires; small fires of this type can be extinguished with water.

Methanol's flammability limits differ from those of gasoline. These properties dictate under what conditions methanol vapors will ignite. In spills on the ground or in the open, methanol does not ignite as readily as gasoline and it burns with a less intense flame.

The flammability hazard in vehicle fuel tanks is also different. In a gasoline fuel tank, the vapor concentration is so high that the vapors are too rich to burn at temperatures above -20°F In a diesel fuel tank there are not enough vapors to support combustion under most conditions. The vapor space in a tank of 100 percent methanol forms an ignitable mixture in the temperature range from 50 to 110°F (10 to 43°C). The risk of accidentally igniting these vapors is mitigated by installing flame arrestors on the fuel tank filler neck and vent. Potential ignition sources are eliminated from the inside of a tank *(17).*

Some methanol buses are equipped with automatic fire suppression systems. These systems were installed on methanol buses because methanol is more flammable than diesel.

Fuel Toxicity

Methanol can cause acute toxic effects from ingesting quantities as small as a few milliliters. Three teaspoonsful (15 milliliters) may be fatal *(18).* Acute toxic effects can also occur from extensive skin exposure or inhalation of high vapor concentrations *(16).* The OSHA exposure limit for methanol vapor in air is 200 ppm. The National Institute for Occupational Safety and Health (NIOSH) recommended time-weighted average (TWA) threshold limit value (TLV) for methanol vapor is 260 mg/m^3, with a 15 minute ceiling of 800 ppm. Investigation of dermal absorption showed that death could result from immersing one's hand in methanol for 4 hours *(18).* Safety training covers precautions that protect personnel from methanol exposure. The use of eye protection and gloves is recommended during fueling and vehicle fuel system maintenance. Seattle Metro and Los Angeles County Metropolitan Transportation Authority have performed formaldehyde and methanol exposure studies. These studies indicated that methanol and formaldehyde exposure levels that are measured during fueling and fuel spill events are within applicable industrial hygiene guidelines. The results of these studies are incorporated into some safety training programs *(19).*

Hazardous Materials

All personnel who handle hazardous materials are required to undergo safety training. Hazardous materials that are encountered in maintenance facilities include fuels, used lubricants, and coolant. Methanol is also a hazardous material. Training for hazardous materials covers spill cleanup and the disposal of waste materials such as used fuel filters and oil filters.

Supply

Methanol is most often produced from natural gas. Most methanol used in vehicles in the United States is a product of Canada or Texas. An expanded methanol market could also make use of methanol from more remote locations such as Indonesia or the Middle East. Methanol produced from biomass has low net carbon dioxide (CO_2) emissions associated with its production and combustion *(20,21).*

Methanol for transit bus fuel is generally obtained from chemical terminals. Two methanol storage terminals are located in California, one in Richmond along San Francisco Bay and the other near Los Angeles. Methanol is delivered in conventional gasoline or diesel delivery trucks. Precautions are taken to prevent contamination of methanol with diesel. Small amounts of gasoline do not adversely affect fuel methanol. Southern California methanol deliveries require less than 50 miles (80 kilometers) of hauling from the storage terminal, located at the Port of Los Angeles in San Pedro. Outside of California, transport distances are often greater, which adds to the cost of methanol supply.

A fuel additive that protects fuel injectors by preventing injector tip plugging in the DDC 6V-92TA methanol engine is blended with methanol. A variety of techniques has been used to blend the additive. In some instances, the additive is added to methanol at the transit agency storage tank when methanol is unloaded into the storage tank. Some blending is performed in the delivery truck prior to transport to the transit agency. Efforts are underway to blend the additive at the storage terminal.

Some methanol buses operate with an ignition enhancer. The product is stored in 50-gallon (260 liter) drums and blended by a method similar to that used for the injector tip cleaning additive.

Estimated Costs--Facility and Operation

Operating costs for methanol are higher than those of diesel fuel because of the fuel's price. On an energy-equivalent basis, compared to diesel fuel, methanol fuel costs are more than 50 percent higher. Requirements for clean diesel and tighter emission controls on diesels may reduce this cost difference. Maintenance and fueling facility requirements for methanol are similar to those of diesel. The purchase price of methanol buses is in the range of $20,000 to $40,000 (1993 US$) higher than that of equivalent diesel buses, making methanol fuel one of the lowest capital cost options among the alternative fuels *(22).*

Environmental Considerations

Methanol engines have the potential to significantly reduce NOx emissions compared to diesel fuel. Additionally, methanol engines produce low levels of particulate matter when compared to diesel engines. Methanol engines also produce somewhat higher formaldehyde emissions, although these can be controlled with a catalytic converter.

Although methanol is miscible with water and biodegrades quickly, methanol spills are an issue because of methanol's listing as a hazardous material. Methanol spills must be cleaned up in accordance with requirements in 40 CFR 261.

ETHANOL

Like methanol, ethanol is a pure organic substance, i.e., a hydrocarbon of fixed composition. By comparison, gasoline and diesel fuel are petroleum products consisting of many different types of hydrocarbon molecules, with no standard or average composition. The physical and chemical properties of ethanol, like any pure substance, are invariant. Physical and chemical properties of diesel and gasoline, on the other hand, can vary with composition, although they are held within a desirable range by controlling refinery basestocks and processes.

Ethanol began receiving serious attention as an alternative fuel for transit buses following development of the DDC 6V-92 methanol engine, since the similar characteristics of ethanol and methanol made adaptation of the methanol engine for ethanol a relatively simple matter. Many ethanol buses in use have modified diesel engines that admit ethanol into the intake manifold, and retain the diesel injection system to initiate combustion and provide idle and part-load operation. This combustion system does not exploit ethanol's full potential as a clean burning fuel. Dedicated ethanol transit buses have been demonstrated on a small scale at a few agencies in recent years *(23,24,25).* Approximately 113 ethanol buses, mostly ethanol/diesel, are in use nationally.

Training

Personnel who operate and maintain ethanol fueled vehicles must have the requisite operating and safety training. Like methanol, ethanol's properties make it different from gasoline and diesel in terms of fire safety. Transit agencies that use ethanol fuel provide specialized training for personnel to address the safety requirements for ethanol. FTA developed a training manual for methanol fuel use *(13)*and the safety procedures described there can also be applied to ethanol. FTA, through TSI, will continue to offer local alternative fuels safety training throughout the United States. Operators also need to be trained in the details of operating ethanol buses.

Storage and Handling

Storage and handling requirements for ethanol are the same as those for methanol. Some different practices may occur with methanol since current ethanol demonstrations are on a smaller scale than methanol demonstrations. Fueling facilities consist of a storage tank and dispenser that can be integrated with the existing fueling facility. Existing steel storage tanks can be retrofitted for ethanol use. Newer alcohol-compatible fiberglass tanks can also be used for ethanol storage. Fuel dispensing equipment usually consists of new ethanol-compatible pumps and dispensers. Ethanol dispensers can be equipped with a mechanically locking nozzle system that delivers fuel at about 40 gal per minute. Conventional automotive nozzles can also be used.

Maintenance Operations Considerations

Ethanol vehicles require some of the same routine maintenance operations as methanol- and conventionally fueled vehicles. The engine components of the DDC 6V-92TA ethanol engine are the same as those for the methanol engine as discussed in the preceding section on Methanol Maintenance Operations Considerations.

Facility Requirements

Requirements for fueling and maintenance facilities for both ethanol and methanol operation are similar to those for diesel fuel.

NFPA requirements for ethanol are similar to those for gasoline and methanol. Fueling facilities must have a Class 1 Division 1 area classification. Most fueling facilities originally meet this requirement and do not need modifications for ethanol. Maintenance garages are required to meet either a Class 1 Division 2 area classification or have sufficiently high ventilation rates in the underground pits and maintenance area.

Vehicle Related Issues

Vehicle related issues that affect ethanol transit bus operation include performance and acceleration, vehicle range, vehicle weight limits, and compatibility of fuel system materials with ethanol. The situation for ethanol buses is very similar to that for methanol buses discussed in the section for methanol in this chapter.

The majority of ethanol engines in service are the DDC 6V-92TA. This engine is identical to the methanol version of the engine other than the electronic programming for fuel control. In some configurations, the engine can use different injectors.

As discussed in the methanol section in this chapter, the choice materials for ethanol fuel systems, as for methanol, are stainless steel and teflon.

Ethanol used as a fuel for transit buses is often mixed with gasoline to discourage intentional ingestion. A common mixture contains 95 percent ethanol and 5 percent gasoline and is known as E95. The performance of E95 ethanol engines is similar to that of comparable methanol and neat ethanol (E100) engines.

The range of ethanol buses depends on the fuel economy and fuel storage capacity. Operating an ethanol bus requires about 1.7 times as much fuel per mile as operating a similar diesel, because of the difference between the two fuels' volumetric energy content. With standard-sized tanks, the range of ethanol buses allows them to operate on most transit routes. The use of rapid-fill fueling nozzles can result in desirable short fueling times.

As for methanol buses, the curb weight for an ethanol bus is about 1,100 lb (500 kg) higher than that of a comparable diesel bus. To agencies having difficulty with full passenger loads and rear axle weight limits, this additional weight may be significant.

Safety

Ethanol differs from gasoline and diesel in its fire hazards. Like methanol, gasoline, and diesel, ethanol is also toxic on ingestion However, lethal doses of ethanol are larger than those for methanol. Temptation for intentional ingestion of ethanol can be mitigated by adding a denaturant. The level of denaturant that is used to make ethanol unpalatable varies among users *(23).* Currently, transit users add 5 percent gasoline.

Fire Hazards

Because of ethanol's higher vapor pressure, ethanol spills are more likely to ignite than diesel spills. Ethanol burns with a slightly luminous flame, however the flames are virtually invisible in open sunlight. As with other fuels, smoking should be prohibited when fueling ethanol vehicles and during any maintenance activities.

Ethanol fire fighting requirements are the same as those for methanol, detailed in the methanol section in this chapter.

The combustion properties of ethanol result in flammability limits that differ from those of gasoline. Ethanol does not ignite as readily as gasoline and it burns with a less intense flame.

The flammability hazard of ethanol in vehicle fuel tanks is also different. In a gasoline fuel tank, the vapor concentration is so high that the vapors are too rich to burn at temperatures above -20 °F (-7 °C). In a diesel fuel tank there are not enough vapors to support combustion under most conditions. The vapor space in a tank of 100 percent ethanol forms an ignitable mixture in the temperature range from 40 to 115°F (4 to 46°C) *(17).* The risk of accidentally igniting these vapors is mitigated by installing flame arrestors on the fuel tank filler neck and vent. Potential ignition sources are eliminated from the inside of a tank by the design of the fuel system.

Fuel Toxicity

Ethanol can cause serious toxic effects from ingesting quantities as small as 100 milliliters. Extensive skin exposure can cause redness and irritation. Inhalation of high vapor concentrations can be toxic, however, inhalation of small quantities is not considered to be toxic *(18).* The American Council of Governmental Industrial Hygienists (ACGIH) exposure limit for ethanol vapor is 1,000 ppm. Appropriate safety training is similar to that for methanol, and includes information and safety practices that enable personnel to guard against ethanol exposure.

Hazardous Materials

Ethanol is a hazardous material because of its properties as a fuel. Personnel who handle hazardous materials receive training in spill cleanup and proper disposal of waste materials such as used fuel filters and oil filters.

Supply

Ethanol is currently produced in the United States from corn and other grain products. Ethanol from sugar cane is imported from South America *(20).*

Ethanol for transit bus fuel is generally obtained through the same distribution channels as those for ethanol as an additive to gasoline. Ethanol is widely available in the Midwest, but in other parts of the country, availability depends on proximity to storage terminals.

The injector tip cleaning fuel additive that is used with methanol for DDC methanol engines is also needed for DDC ethanol-fueled engines. Blending considerations are detailed in the methanol section in this chapter.

Estimated Costs-Facility and Operations

Operating costs for ethanol are higher than those of diesel fuel because of the fuel's price. Compared on an energy content basis to diesel fuel, ethanol fuel costs are more than twice as high, even when grain production is subsidized *(18).* The cost impact of new requirements for reformulated diesel fuel and tighter emission controls on diesels may reduce this cost difference in the future. Maintenance and fueling facility requirements for ethanol (and methanol) buses are similar to those of diesel, so no significant cost difference exists in these areas. The purchase price of ethanol buses, like methanol buses, is in the range of $20,000 to $40,000 (1993 US$) higher than that of diesel buses. Therefore, like methanol, ethanol fuel is one of the lowest capital cost options among the alternative fuels *(26).*

Environmental Considerations

Ethanol engines have the potential to significantly reduce NO_x emissions compared to diesel fuel. However, NO_x emissions for the current DDC ethanol engine are not as low as those for the methanol configuration. This discrepancy could be due to engine tuning parameters. Ethanol engine emissions of formaldehyde and acetaldehyde can be controlled with catalytic converters.

While ethanol is miscible with water and biodegrades quickly, spills are properly handled by collection and incineration.

COMPRESSED NATURAL GAS

While CNG has received interest as a vehicle fuel for several decades, factory-built engines for transit buses have only recently become available for this fuel. Early transit demonstration projects with CNG used manufacturer's prototype or converted CNG engines in relatively small numbers. Since 1992, the Cummins L10-240G engine has been available as a factory built, emissions-certified natural gas engine for transit buses. Other competing engines are expected to become available in the near future. More than 300 CNG buses are now being used in transit agencies across North America, in demonstration projects and in conversions of some entire fleets *(7,8,2 7).*

Training

Operating and safety training is required for personnel operating and maintaining CNG buses. Because of the gaseous nature of CNG and the fact that it is stored under high pressure, handling characteristics are significantly different from more familiar liquid fuels. CNG bus operators must be aware of the reduced range of their vehicles and the location of fueling sites in their area. Fueling procedures must be formalized and transmitted to operators to safely dispense fuel from CNG fuel stations. Often the fueling procedure will vary depending on the location of the fueling facility. It is essential for drivers to know the procedures to follow in the event of a leak, what to do if they run out of fuel, and any vehicle-specific peculiarities of the CNG bus relating to an accident, towing, or fire. Safety of the driver and passengers is paramount. FTA has developed a safety training guide for CNG transit bus operations *(28).*

Storage and Handling

CNG typically is stored in high-pressure cylinders under maximum pressures of 3,000 to 4,800 pounds per square inch (psi) (20 to 32 MPa). All devices designed to store or transmit CNG must be capable of withstanding from 1.5 to 4 times the maximum working pressure of the gas *(29)* and be designed for natural gas service. Labeling criteria apply for devices such as cylinders, valves, hoses, regulators, and filters. NFPA 52 Section 2-8.4 states that cast iron, plastic, galvanized aluminum, and copper alloys exceeding 70 percent copper are not approved for compressed natural gas service, because these materials lack the necessary strength or resistance to corrosion required for CNG service. Stainless steel is the material of choice for CNG piping and components because of the corrosive nature of water and sulfur compounds that can be found as contaminants in CNG.

Large stationary CNG tanks of the type used for fueling facilities are typically manufactured from steel and are qualified under American Society of Mechanical Engineers (ASME) pressure vessel code, Section VIII, Division 1 and Appendix 22. These pressure vessels are rated as high as 4,900 psi (32.7 MPa).

Maintenance of compressors and filter/coalescers is an important consideration to preclude the introduction of compressor lubricating oil into the vehicle fuel systems. Interaction with the fire department is an essential step in the planning of any new CNG fueling station in order to satisfy any local requirements that the officials may feel are needed. NFPA 52 *(5)* is the standard most fire departments use to delineate the requirements for CNG equipment. Earthquake restraints are needed for cylinder storage in California.

Maintenance Operations Considerations

CNG vehicles require many of the same routine maintenance operations as conventionally fueled vehicles. However, the pressurized nature of the fuel and its different density and ignition properties require special maintenance procedures for CNG vehicles.

Since the fuel is under pressure, a serious leak can expel a significant amount of natural gas in a short time. Mechanics must be made aware of the dangers of loosening a pressurized tube or component. Some maintenance shops routinely turn off all CNG cylinders and depressurize the fuel system before initiating maintenance work on CNG vehicles within their shop. Elevated ignition sources such as radiant heaters can ignite a rising plume of leaked natural gas within a maintenance facility. Adequate ventilation or elimination of the ignition source is necessary to ensure that a fire hazard cannot result from leaked gas.

Mechanics' training must include awareness that only approved replacement components should be used when servicing CNG systems. Mechanics must also be trained in the identification, location, and repair of leaks. In the event of a major leak within a maintenance facility, a predetermined evacuation plan can help ensure that injury does not occur from fire or asphyxiation.

Facility Requirements

NFPA requirements for service garages do not directly address natural gas fueled vehicles. Modifications to buildings need to be evaluated on a case by case basis.

A well-designed CNG maintenance facility has explosion-proof devices and wiring in the areas where CNG buses will be maintained. Building ventilation is activated by methane detectors located near the ceiling. An alternative to explosion-proof devices and wiring is a strict policy of closing off vehicle CNG tanks and purging the fuel system before performing indoor maintenance activities.

Routine maintenance activities can be performed outdoors as well. Roof ventilators are desirable to dissipate any natural gas that may be vented in the maintenance area. Spare parts for CNG buses are stored in a clean dry area indoors with any dust caps left in place. CNG fueling areas require a fire extinguisher and emergency shut-off switch.

Fueling facility requirements are covered by NFPA 52 *(5).*

Vehicle Related Issues

Range is typically the vehicle operating parameter that becomes an issue in CNG projects. Fueling time can also be an issue if a slow-fill fueling system is used or if operating schedules conflict with the time required for fueling operations. Recently installed large-scale bus CNG fueling stations, such as those at LACMTA in Sun Valley and SRTD in Sacramento, have demonstrated that CNG fueling times can be short enough as to not interfere with the overall operation of the bus fleet. Fueling times of 4 minutes have been reported at Sacramento. A drawback of fast filling is that the rapid temperature rise of the transferred natural gas effectively reduces the gas density, and hence the quantity of fuel loaded, assuming the same final pressure as for a slow-fill *(30).*

Size and placement of CNG tanks is an issue for virtually all CNG vehicles. Because the tanks are necessarily round, they cannot be custom fit into tight areas. Tanks are larger than energy equivalent diesel tanks because of the lower energy density of the fuel. Vehicular CNG tanks are manufactured of steel, fiberglass-reinforced steel, fiberglass-reinforced aluminum or composite construction. These tanks are designed to handle 3,000 or 3,600 psi (20 or 24 MPa). CNG tanks are heavy in relation to gasoline fuel tanks and can effectively reduce the payload of vehicles. All-composite tanks offer the lightest weight and all-steel tanks are typically the heaviest. LACMTA has reported a weight penalty of 3,300 lb. (1500 kg) versus diesel buses for their CNG buses fitted with reinforced aluminum CNG cylinders. While approval of the new all-composite cylinder designs is not yet certain, they could reduce this weight penalty by about one-half.

Performance and drivability of a CNG vehicle can be made equal to that of a conventionally fueled vehicle.

Safety

CNG differs from liquid fuels in its hazards. In addition to fire hazards, physical hazards exist because of the high pressures at which CNG is stored.

Fire Hazards

Natural gas is lighter than air and will rise from the location of a leak. Trained personnel must be aware of the ways to detect a CNG leak. A small natural gas leak may be detectable only by the smell of the odorant or by a methane detector which is needed because people frequently exposed to natural gas often lose their capacity to notice small concentrations after some time. Larger leaks may also be detected by their sound or by the appearance of frost.

Smoking is prohibited when fueling CNG vehicles or working on their fuel systems. Work practices and facility design must eliminate potential ignition sources where natural gas is handled or where leaked natural gas may accumulate (e.g., near the ceiling). Natural gas is flammable in air at concentrations between 5 and 15 percent volume *(18).* Any natural gas leak is considered a fire hazard, since a flammable concentration exists at the interface between a gas plume and the surrounding air.

Specific fire fighting practices apply to natural gas. Properly used halon and CO_2 fire extinguishers can effectively starve a small natural gas fire for oxygen, and thus extinguish it. Most natural gas buses are equipped with automatic fire suppression systems. These systems are desirable because natural gas is more flammable than diesel.

High Pressure

The high storage pressure of CNG poses certain hazards which are minimized by proper equipment and training. A high-pressure fitting, if loosened while under pressure, could become a missile. Skin contact with a high-pressure gas jet could result in a gas embolism in the bloodstream. Training that covers these hazards enables personnel to avoid them.

Other Hazards

There is no danger of ingestion of CNG because of its gaseous nature. Asphyxiation is possible in a closed environment due to displacement of oxygen. Absorption through the skin is not thought to be a problem.

Supply

Natural gas is supplied by local utilities and installation of compressor systems is typically coordinated through those utilities. Natural gas is produced within the continental United States and Alaska, giving it appeal as a domestic fuel. This can be advantageous in the event of an interruption in oil supply. Some sources believe that there is a 60- to 100-year supply of natural gas available domestically. These supply numbers vary depending on the source of the calculation.

Because natural gas is a mixture of many gases, and composition varies seasonally and by region, there are ongoing discussions as to what are acceptable properties for natural gas. There is currently no standard for composition of vehicle natural gas. Areas of interest are water content, sulfur content, heating value, particulate contamination, and Wobbe index.

The Wobbe index of a natural gas is proportional to the chemical energy admitted through a metering device per unit time at a constant supply pressure *(31,32).* The Wobbe index varies with natural gas composition, and is monitored by utilities and controlled by adding hydrocarbon gases or inert dilutents. The gas utilities maintain the Wobbe index of their natural gas within a range determined to be appropriate for the performance and safety of gas appliances. The control of the Wobbe number exercised by the utilities is thought to result in acceptably small fuel-to-air ratio excursions in natural gas engines *(32).*

The composition of hydrocarbons in natural gas affects its combustion performance in CNG engines. A higher methane content usually results in a higher octane number and more resistance to knock. Natural gas with methane content above 93 percent is usually sufficient for knock-free engine operation. Composition of natural gas has been found to be reasonably consistent in most areas of the United States. Certain areas may have uniquely different compositions *(33).*

CNG may contain corrosive agents such as carbon dioxide or hydrogen sulfide in combination with water, all of which occur naturally in some natural gas basestocks. Carbon steel is susceptible to stress corrosion cracking, if used in high-pressure applications. Industry standards set allowable levels for these contaminants, and NFPA-approved CNG equipment is designed to operate with the allowable levels present *(5,33).*

The gas utility companies introduce an odorant chemical (typically methyl mercaptan) into the natural gas to act as a leak indicator. NFPA 52 requires this odorant to be present in any vehicular CNG.

Estimated Costs--Facility and Operation

CNG is typically less expensive than gasoline or diesel fuel on an energy equivalent basis. Data in the October 1993 issue of *Natural Gas Fuels* magazine indicate that, on average, CNG sells for about 60 percent of the diesel price. This survey included data from nine sites in the United States and two in Canada. Natural gas prices depend on local rate structures and range from \$0.45 to \$0.90 per 100 standard cubic feet for natural gas with compression (\$0.16 to \$0.32 per standard cubic meter) *(22).* Because efficiency of throttled natural gas engines is inherently less than unthrottled diesel engines, CNG engines have 15-25 percent higher energy consumption in use *(8).* This partially offsets CNG's cost advantage based on energy content alone.

CNG fueling facilities are expensive and are often underwritten by utilities who hope to recoup their investments by selling more natural gas. Two options exist for fueling stations: slow-fill and fast-fill. Slow-fill refueling times can range from 30 minutes to 10 hours, depending on compressor capacity and number of buses being served. Costs for installing the facility are tied to compressor size, and can run from under \$10,000 to \$400,000 (1993 US\$). Fast-fill stations also encompass a wide range of capacities but are typically more expensive than slow-fill stations because of the addition of high pressure storage bottles. Refueling times are typically 4 to 20 minutes. Construction costs for a fast-fill station may run from \$250,000 to more than \$7 million (1993 US\$) depending on the capacity required.

Environmental Considerations

Natural gas has the potential to significantly reduce NO_x emissions when compared to gasoline or diesel fuel. Additionally, natural gas produces very low levels of particulate matter when compared to diesel fuel. Reactive hydrocarbons are lower than those of gasoline and diesel vehicles. Carbon monoxide from natural gas vehicles can be as much as 90 percent lower than from gasoline vehicles. Carbon dioxide emissions are typically lower than those of gasoline vehicles and comparable to diesel emission levels.

Because natural gas is in the gaseous state, a spill will not result in significant localized contamination but will dissipate in the atmosphere. While methane is a greenhouse gas and contributes to global warming when released to the atmosphere, proper use of CNG should result in no significant quantities of methane being released over the long term.

LIQUEFIED PETROLEUM GAS (LPG)

LPG is a gaseous refinery by-product consisting mainly of propane with smaller amounts of propylene, butane, and other light hydrocarbons. It is gaseous at standard conditions, but is usually handled as a pressurized liquid.

LPG has received interest as a vehicle fuel for several decades. However, factory-built heavy-duty engines using this fuel are not available for transit buses. Transit demonstration projects with LPG are using prototype or converted LPG engines. Ford is now installing their factory built, emissions-certified LPG engine in certain truck chassis; this engine may be suitable and could become available for paratransit buses. Approximately 250 LPG buses, mostly paratransit, are now being used in transit agencies across North America (7).

Training

Operating and safety training is required for personnel operating and maintaining LPG vehicles. Because of the gaseous nature of LPG and the fact that it is stored under moderate pressure, handling characteristics are significantly different from more familiar liquid fuels.

Drivers must be aware of procedures to follow in the event of a leak, what to do if they run out of fuel, and be alerted of any vehicle specific peculiarities of the LPG vehicles. Drivers and mechanics should be made aware of the safety related aspects of LPG. A training manual is available for LPG vehicle operators *(34).*

Storage and Handling

LPG is typically stored in the liquid phase in moderately pressurized cylinders under pressures of 110 to 150 psi (760 to 1030 kPa). Fuel tanks for LPG are typically manufactured of carbon steel and are similar to compressed air tanks in construction. The tanks are equipped with pressure relief devices typically set in the vicinity of 375 psi (2600 kPa). Working pressure for the vehicular tanks is typically 250 psi (1720 kPa). Tanks are manufactured in a wide variety of sizes to suit different applications. A segment of the populace has handled LPG either for portable barbecue grills, propane torches, or recreational vehicle use.

Large stationary LPG tanks of the type used for fueling facilities are typically manufactured from steel and are qualified under ASME pressure vessel code. These pressure vessels are rated for working pressures of 250 psi (1720 kPa) and are available in sizes ranging up to 30,000 gallons (110 000 liters).

Fuel is delivered to stationary fueling facilities via tank trucks with typical volumes of 10,000 gallons (36 500 liters). The LPG is transferred from the tank truck to the fueling facility by compressing the vapor from the stationary tank and putting it atop the liquid in the tank truck. This forces liquid from the tank truck into the stationary tank, resulting in little leakage to the atmosphere.

Fuel is pumped from the fueling facility to bus fuel tanks, which are vented to allow gaseous fuel to escape. The fuel transfer pump is turned on and remains on until liquid fuel begins to spill from the vent on the bus fuel tank. The pump is then shut off, the vent closed and the fueling hose disconnected. This process results in some venting of LPG to the atmosphere. Newer LPG fuel tanks have a valve that shuts off fueling automatically and does not require venting LPG to the atmosphere.

As with any new fuel installation, interaction with the fire department is an integral part of planning an LPG fueling station in order to satisfy any local requirements that the fire officials might impose. NFPA 58 *(5)* is the standard most fire departments use to delineate the requirements for LPG equipment. Earthquake restraints are needed for stationary LPG facilities in California.

Maintenance Operations Considerations

LPG buses require many of the same routine maintenance operations as conventionally fueled buses. The pressurized nature of the fuel and the differences in density and ignition properties from conventional fuel require some special maintenance procedures for LPG vehicles.

Because the fuel is under pressure, a serious leak can expel a significant amount of LPG in a short time. LPG vapors are heavier than air and will pool in low areas, such as maintenance pits. Adequate ventilation and elimination of ignition sources is necessary to ensure that a fire hazard cannot result from leaked gas.

Only approved replacement components are used when servicing LPG systems. This is stressed in mechanics' training, which also emphasizes the identification, location, and repair of leaks. In the event of a major leak within a maintenance facility, a predetermined evacuation plan can help ensure that injury does not occur from fire or asphyxiation.

Facility Requirements

NFPA does not directly address requirements for buildings that service LPG vehicles. However, the following measures are taken for safety when vehicles are indoors. A well-designed maintenance facility has explosion-proof devices and wiring in the areas where LPG buses are maintained. Building ventilation is sufficient to remove LPG gas from ground level. An alternative to explosion-proof devices and wiring is a strict policy of closing off vehicle LPG tanks and purging the fuel system before performing indoor maintenance activities.

Routine maintenance activities can be performed outdoors as well. For protection from contamination and moisture, spare parts for LPG vehicles are kept in a clean dry area indoors and their dust caps left in place.

Fueling areas require a fire extinguisher and an emergency shutoff switch. Fueling facility requirements are delineated in NFPA 58.

Vehicle Related Issues

Vehicle range of LPG buses may be less than that of diesel buses if LPG tanks are not sized to compensate for the reduced energy density of the fuel, relative to diesel. Fueling time is typically comparable to fueling a gasoline or diesel bus and is therefore not an issue.

Size and placement of LPG tanks can be an issue for some buses. The tanks are necessarily round and cannot be custom fit into tight areas. They are larger than energy equivalent gasoline or diesel tanks because of the lower energy density of the fuel. The higher strength and larger size of LPG fuel tanks impose a moderate weight penalty compared to equivalent diesel tanks. For example, a weight differential of 360 lb (160 kg) was recorded for similar LPG and diesel buses in a clean fuel comparison project (7).

Performance and drivability of an LPG vehicle can equal that of a conventionally fueled vehicle.

Safety

LPG is similar to other liquid fuels in some of its hazards. Additional hazards result from the pressure and properties of LPG.

Fire Hazards

LPG at ambient conditions is heavier than air and will descend from the location of a leak. Trained personnel must be aware of the ways to detect an LPG leak. Like natural gas, a small LPG leak may be detectable only by the smell of the odorant or by a combustible gas detector. Larger leaks may also be detected by their sound or by the appearance of frost.

As with all fuels, smoking is prohibited when fueling LPG vehicles or working on their fuel systems. Safe work practices and facility design can eliminate potential ignition sources where LPG is handled or where leaked gas may accumulate (e.g., at floor level, in pits, and in trenches). As with natural gas, any LPG leak is considered a fire hazard, since a flammable concentration exists at the interface between a gas plume and the surrounding air.

Specific fire fighting practices apply to LPG. Properly used halon and CO, fire extinguishers can effectively starve a small LPG fire for oxygen, and thus extinguish it.

Some LPG buses in demonstration projects are equipped with automatic fire suppression systems. These systems are desirable because LPG is more flammable than diesel.

Pressure

The storage pressure of LPG poses certain hazards that are minimized by proper equipment and training. A pressurized fitting, if loosened while under pressure, could become a missile. Skin contact with a pressure-fed gas jet could result in a gas embolism in the bloodstream. More likely is a freeze burn caused by the drop in temperature at the point of a leak. Training that covers these hazards enables personnel to avoid them.

Other Hazards

Ingestion of LPG is unlikely because of the fuel's tendency to vaporize at ambient conditions. Asphyxiation is possible in a closed environment due to displacement of oxygen. Absorption through the skin is not considered a problem.

Supply

LPG is supplied by independently owned and operated companies. Often one area is served by several independent companies that will work with customers to install fueling systems. LPG is produced within the continental United States as a by-product of natural gas and oil production. It is also available from overseas locations via large ships. Net imports of LPG to the United States are approximately 9 percent of the total supply.

The independent LPG companies introduce an odorant chemical into the gas to act as a leak indicator. This odorant should be present in any vehicular LPG.

Estimated Costs-Facility and Operation

LPG is typically priced on a par with diesel fuel on an energy equivalent basis. Since efficiency of throttled LPG engines is inherently less than unthrottled diesel engines, LPG engines have 15-25 percent higher energy consumption in use *(7)*. Therefore, up to 25 percent higher operating costs should be expected for LPG buses.

LPG fueling facilities are moderately expensive and are often underwritten or leased by independent LPG companies who hope to recoup their investments by selling more LPG.

Environmental Considerations

LPG has the potential to reduce NO_x and hydrocarbon emissions when compared to gasoline or diesel fuel. Additionally, LPG produces low levels of particulate matter when compared to diesel fuel. Since LPG at ambient temperature and pressure is in the gaseous state, a spill will not result in significant localized contamination but will dissipate. Because of the compressed nature of the gas very little evaporative emissions are associated with LPG. Some venting occurs with fueling procedures in older LPG vehicle tanks.

LIQUEFIED NATURAL GAS

Liquefied natural gas (LNG) is produced by cooling natural gas and purifying it to a desired methane content. LNG is stored under moderate pressure in insulated tanks, at or near its boiling point (-260°F [-162°C] at 1 atmosphere). It is a relative newcomer as an alternative fuel for transit buses, so equipment, fuel supply systems, safety codes, and published information are not yet readily available.

Training

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. Depending on its temperature, LNG vapor can be heavier or lighter than air, so vapor from spilled LNG may find its way to any part of an enclosed space. Published training manuals are not yet available, but a report entitled "An Introduction to LNG Vehicle Safety" *(35)* is forthcoming from the Gas Research Institute. FTA is also developing a training manual to be published in 1994 and will offer TSI training courses on LNG.

Storage and Handling

LNG storage and dispensing systems are subject to requirements for minimum separation from other land uses under NFPA and Uniform Fire Code (UFC) regulations *(5,36)*. 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-top channel. Two containment options are available: containment at the location of the storage tank, or remote impoundment. The containment system for a non-fire protected system must accommodate the combined volume of containers it serves; if fire protected, the system must contain 110 percent of the volume of the largest container.

Refueling operations require operator awareness of and protection from cryogenic hazards. Nozzles are continually being developed to improve reliability to a satisfactory level. With its high energy density and with appropriate flow rates, LNG refueling can be streamlined to match diesel fueling turn-around times. However, with current fueling facility technology, from a standby station condition, a cool-down cycle is necessary before vehicle fueling can begin. The purpose is to cool the fuel plumbing and transfer lines to LNG temperature to prevent excessive vapor from forming during bus fueling. Once cool-down has been performed, successive buses can be fueled without interruption.

Maintenance Operations Considerations

The characteristic properties of LNG introduce new hazards into bus maintenance operations. Any indoor maintenance must be done with the assurance that leaks are not present, and that the vehicle fuel system pressure is well below the set-pressure for venting so that the system will not need to vent while indoors. Attention to system pressure is required while the bus is indoors to ensure that indoor venting is avoided if the pressure approaches the pressure relief setting. An option to consider in some cases is offloading all fuel before bringing the vehicle indoors.

An understanding of LNG hazards, the use of methane leak detectors, and the repair of LNG leaks are required knowledge for maintenance personnel.

Facility Requirements

Two issues need to be addressed for indoor handling of LNG: ventilation and elimination of likely ignition sources. NFPA 59a *(5)* outlines requirements and various options for providing safe ventilation, while UFC Article 29 *(36)* and NFPA 70 *(5)* regulate potential ignition sources. Methane detectors can be used to activate high-flow ventilation systems and to disable facility electrical power as needed to guard against potential combustion of leaked methane.

Vehicle Related Issues

LNG's use as a vehicular fuel is being evaluated in current demonstrations. Favorable factors are its potential for low emissions, relatively high energy storage density, and available uniform composition. Issues currently receiving attention are equipment availability, cryogenic liquid handling problems, lack of LNG sources in many areas, and potential composition drift (weathering) due to settling of heavier hydrocarbons when LNG is stored.

Composition drift can be avoided by specifying suitable purity, and by attention to projected throughput of an LNG fuel facility at the design stage.

Performance and drivability of an LNG bus can be made equal to that of a conventionally fueled vehicle, as can fueling time and range. A major difference between an LNG bus and vehicles using other fuels is that fuel venting becomes necessary after the bus is parked a certain length of time. Current tank designs allow holding times of 8 to 21 days before venting occurs. Normal vehicle operations consume fuel from the tank at a rate which more than compensates for the pressure rise due to heat transfer.

Safety

In addition to fire hazards, LNG poses some different and unusual hazards relative to other fuels. However, awareness of these hazards, proper training, suitable equipment, and good work practices can result in a level of safety and a safety record that equals conventional fuels.

Fire Hazards

Natural gas is lighter than air and will rise from the location of a leak. As LNG is not odorized, a small leak may be detectable only by a methane detector. Larger leaks may also be detected by their sound or by the appearance of frost.

Smoking is prohibited when fueling LNG vehicles or working on their fuel systems. Work practices and facility design must eliminate potential ignition sources where natural gas is handled or where leaked natural gas may accumulate (e.g., near ceiling). Natural gas is flammable in air at concentrations between 5 and 15 percent volume *(18).* Any natural gas leak is considered a fire hazard, since a flammable concentration exists at the interface between a gas plume and the surrounding air.

Specific fire fighting practices apply to natural gas. Properly used halon and CO_2 fire extinguishers can effectively starve a small natural gas fire for oxygen, and thus extinguish it. Most natural gas buses are equipped with automatic fire suppression systems. These systems are desirable because natural gas is more flammable than diesel.

Cryogenic Hazards

LNG boils at -260°F (-162°C) and is handled at or below this temperature. Inadvertent skin contact with leaked LNG or with hardware that is cooled by LNG can freeze tissue and inflict serious cryogenic burns. Training that covers cryogenic hazards enables personnel to avoid them.

Other Hazards

Ingestion of LNG is an unlikely scenario because of the fuel's tendency to vaporize at ambient conditions. Asphyxiation is possible in a closed environment as a result of displacement of oxygen. Absorption through the skin is not considered a problem.

Supply

Supplies of LNG are generally located at major ocean terminals because much of the gas is produced overseas. However, the Texas users rely on domestic sources and storage areas are nearer the transit facilities. On-road use of LNG has not yet generated its own infrastructure, so LNG users are obliged to tap into the existing one. This is relatively easy if an LNG terminal is nearby. If there is not a nearby terminal, overland shipments from the nearest terminal are probably the best option. A burgeoning vehicle market for LNG may eventually cause gas liquefaction plants to be built where adequate markets exist.

An advantage of LNG is that purity can be specified when it is purchased from the supplier. High purity (i.e., high methane content) minimizes or avoids problems of heavier hydrocarbons settling out in storage and results in decreased engine problems.

Estimated Costs-Facility and Operation

Estimated cost of a fuel storage and dispensing facility with 20,000 gallons (73 000 liters) LNG storage is about $800,000 (1993 US$). However, many of these current costs relate to development and should decrease over time. Costs for upgrading existing buildings to accommodate LNG vehicles will depend on the building design and local factors. These costs should not differ greatly from those incurred in adapting existing buildings to fuels such as methanol or CNG.

The cost of LNG is close to that of diesel on an energy basis *(37).* Local diesel fuel pricing and delivered LNG cost are important variables in making a cost comparison. Some tests show that the efficiency of throttled natural gas engines is inherently less than unthrottled diesel engines and that natural gas engines have 15-25 percent higher energy consumption in use *(7)*. Any storage tank venting of natural gas, if not recovered for other use, will increase the cost of using LNG.

Environmental Considerations

Natural gas has the potential to significantly reduce NO_x emissions when compared to gasoline or diesel fuel. Additionally, natural gas produces very low levels of particulate matter when compared to diesel fuel. Reactive hydrocarbons are lower than those of gasoline and diesel vehicles. Carbon monoxide from natural gas vehicles can be as much as 90 percent lower than from gasoline vehicles. Carbon dioxide emissions are typically lower than those of gasoline vehicles and are comparable to diesel emission levels.

With respect to other environmental considerations, LNG is an attractive fuel. The hazard to the environment posed by spilled LNG is small, as the safety containment provisions keep the fuel in a confined area until it vaporizes and dissipates. While an LNG accident involving combustion could conceivably do harm, LNG itself is not a toxic threat to soil or groundwater systems. Methane released to the atmosphere is not considered to be a significant contributor to ozone formed in smog reactions. While methane is a greenhouse gas and contributes to global warming when released to the atmosphere, proper use of LNG should result in no significant quantities of methane being released over the long term.

The general characteristics of these alternative fuels are summarized in Table S-1 in the Summary.

CHAPTER FOUR

CASE STUDIES

Five transit agencies were investigated in depth as case studies in this synthesis report. The five agencies were chosen mainly for their experience with one of the alternative fuels under study in this project. Profiles of the five case study agencies are shown in Table 2.

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY (LACMTA)--METHANOL

LACMTA began taking delivery of methanol buses in 1989 and has since become a large scale user of methanol fuel in a transit application, with 333 neat methanol buses and 12 converted methanol buses (that use methanol with an ignition enhancer) in service in 1993. Their experience has validated the safety concepts implemented at the beginning of their methanol use, and has led to the development of additional safety and health precautions. Noteworthy steps taken by LACMTA to maximize safety of their methanol bus operations are discussed in the following paragraphs.

Safety Codes

LACMTA has followed applicable Federal Motor Vehicle Safety Standards (FMVSS) and DOT codes for their methanol buses, and applied City of Los Angeles fire codes for methanol bus refueling and maintenance.

Facility Modifications

Awareness of methanol's higher vapor pressure in relation to diesel fuel, and the implications on fire and health risks caused LACMTA to increase pit ventilation, install explosion-proof lighting, and add water hoses and pit drains in their methanol maintenance facilities. All future construction, regardless of intended fuel, will meet LACMTA's standard for accommodating methanol.

Safety Training

Safety training for methanol fuel at LACMTA is given to operators, mechanics, their supervisors, and others as needed. Training

TABLE 2
PROFILES OF THE FIVE CASE STUDY AGENCIES

Transit Agency	Los Angeles County Metropolitan Transportation Authority (LACMTA)	Pierce County Public Transportation Benefit Area Authority Corp. (Pierce Transit)	Metropolitan Transit Authority of Harris County (Houston Metro)	Orange County Transportation Authority (OCTA)	Greater Peoria Mass Transit District (GP Transit)
Location	Los Angeles County, CA	Takoma, WA	Harris County, TX	Orange County, CA	Peoria, IL
Service Area in Sq. Miles (km^2)	1,442 (3,691)	275 (704)	1,279 (3,274)	800 (2048)	127 (325)
Number of Staff	9,000	576	3,400	1,600	125
Annual Miles (km)	100,000,000 (160 000 000)	7,871,000 (12 593 600)	N/A	20,000,000 (32 000 000)	1,500,000 (2 400 000)
No. of Buses	2,500	161	1,100	760	49
Annual Ridership	409,000,000	10,443,000	63,000,000	44,000,000	1,600,000
Case Study Fuel	Methanol	CNG	LNG	LPG	Ethanol
No. of Case Study Alt. Fuel Buses					
Fullsize	345	30	240	2	14
Para-transit	0	19	94	172	0

consists of a classroom session with a video presentation based on the Urban Mass Transportation Administration (UMTA) (now FTA) "Training Manual For Methanol Fuel Use In Transit Operations" *(13).* A copy of this manual is given to all participants. Primary focus of the LACMTA training program is given to methanol toxicity via ingestion or skin absorption and methanol's low flame luminosity. Refresher training is given yearly.

Refueling Stations

Neat methanol (M100) fueling is done at three separate operating divisions of LACMTA, and methanol fuel with an ignition enhancer is used in converted diesel buses at one other division. Methanol dispensers have been added to all lanes of existing fuel stations at these bases (Figure 1). Mechanically locking refueling connectors are used, with separate fuel and vapor recovery nozzles. The nozzles' design prevents fluid from being transferred unless the device is properly connected. Different designs are used for the fuel and vapor connectors, to prevent misapplications (Figures 2, 3 and 4). Special lug designs ensure correct application of fueling connectors to M100 methanol buses, retro-fitted methanol buses, or diesel buses. During fueling, the bus is automatically grounded to the dispenser by virtue of steel reinforcement in the dispenser hose. As a further precaution against a static electrical

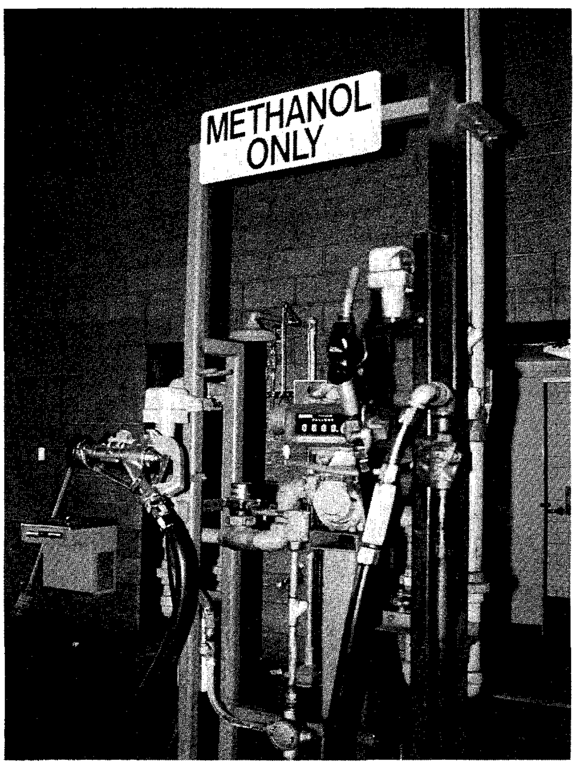

FIGURE 1 Methanol dispenser.

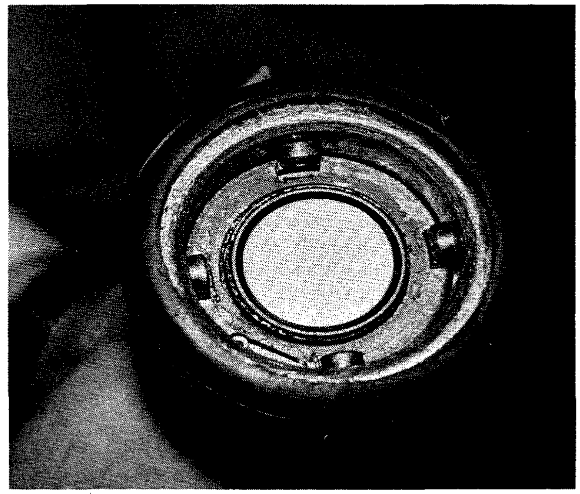

FIGURE 2 Methanol fuel nozzle.

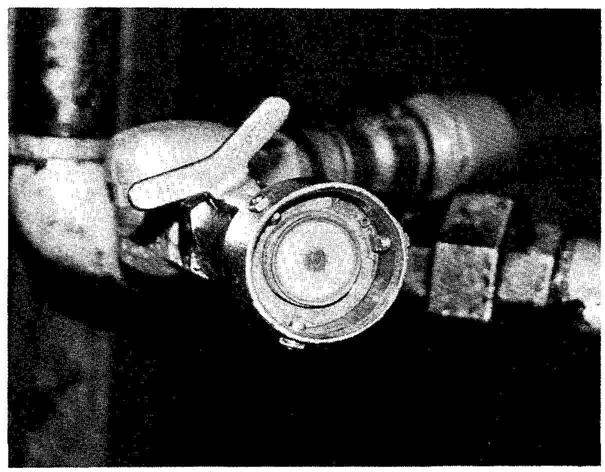

FIGURE 3 Vapor return nozzle.

charge build-up and subsequent discharge during refueling, a redundant ground strap is connected to the fuel tank as the first step in the filling procedure. The dispensers are also equipped with safety break-away fittings, which are designed to break apart before any other component fails, in the event of vehicle roll-away while the nozzle is connected. Vapor displaced from the bus fuel tank during filling is returned via the vapor hose to the underground supply tank. Vapor recovery is also effected during filling of the supply tank by a tanker truck. Should pressure or vacuum in the underground tank exceed set levels, a two-way relief valve equalizes pressure with the atmosphere via a stack projecting above the fuel facility. These are considered emergency vents, as their activation should not occur during normal operation of the fuel station. Mechanical leak detectors are provided to interrupt

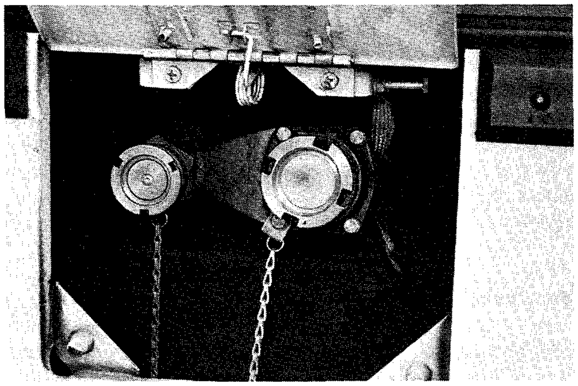

FIGURE 4 Bus vapor and fuel connectors.

the flow of fuel from the supply tank to the dispenser, should a leak develop. Installed emergency power shut-off switches, fire extinguishers, and personnel emergency shower/eyewash stations serve to counteract the hazards of a methanol incident, should one occur.

On-Board Fire Suppression

LACMTA methanol buses are equipped with a combined infrared fire detection and halon fire suppression system. Detection of infrared energy on both of two key wavelengths by any of three strategically located sensors in the engine compartment activates one of two 25 lb (10 kg) halon fire extinguishers, via two nozzles placed where their plumes are thought to be most effective (Figure 5). An alarm is simultaneously relayed to the operator, who has 10 seconds to bring the coach to a stop in a safe location. After 10 seconds, the system disables the methanol fuel pump, effectively shutting the engine down. The operator may override this shutdown

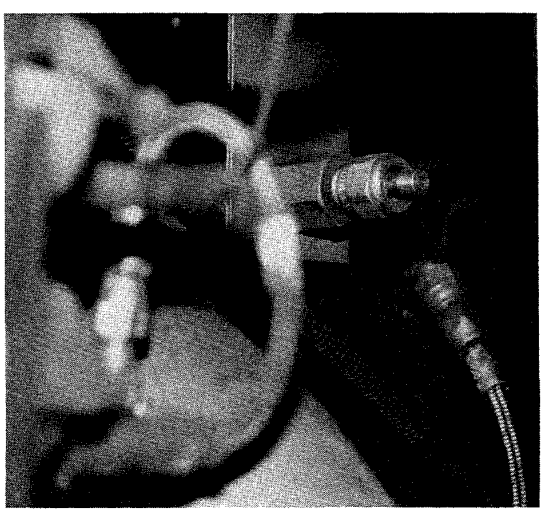

FIGURE 5 Halon nozzle.

down if circumstances warrant. Fifteen seconds after the initial alarm, a second 25 lb (10 kg) halon bottle is activated via the same two nozzles. Restarting of the bus is disabled at this point. LACMTA has recorded one instance of this system being deployed in response to an engine bay fire. The system worked as designed, and damage was limited to an engine wiring harness. An additional detection/suppression capability is provided in the fuel filter and cooler area of the buses in LACMTA's most recent methanol bus procurement. Located in this area are high-pressure fuel, potential leak or rupture points, and electrical motors. If a fire is detected in the fuel cooler area, an alarm is relayed to the operator, a 25 lb (10 kg) dry chemical fire extinguisher is deployed, and the 10-second fuel pump shutdown sequence begins. Future bus procurements will specify explosion-proof equipment only, in addition to fire detection/suppression in this area.

On-Board Fuel Systems

Methanol bus fuel tanks incorporate several features that minimize the chance of spills, leaks, or ignition sources entering the vapor space of the tank. The mechanically locking fueling and vapor connectors incorporate a type of flow control, poppet valves that remain closed until the nozzles are properly attached and locked in place (Figure 4). The fuel filler neck extends to the bottom of the tank, so that it is always immersed in liquid methanol. A single atmospheric vent is provided, which is fitted with a 1/2-in. National Pipe Thread (NPT) stainless steel spark arrestor. The vapor return fitting incorporates a level control valve which, during fuel dispensing, closes when the fuel reaches the desired level. The fuel delivery nozzle is equipped with a pressure sensor that shuts off the flow of fuel in response to the back pressure caused by the closed level control valve. The level control valve also prevents fuel spillage from the vapor return fitting in the event of a vehicle rollover, as the valve will close under the effect of gravity if inverted. On LACMTA's original 30 methanol buses, a fuel door interlock switch prevents engine starter operation while the fuel filler door is open, the objective being to prevent motion of the bus while the fuel hoses are connected. This feature was deleted from LACMTA's latest methanol bus procurement for design reasons related to its reliability as the switch tended to be damaged in use.

Two of LACMTA's early methanol buses experienced fuel tank weld failures, one of which resulted in a sizable fuel spill. As a result, all coaches of the early procurement were subjected to dye inspections of fuel tank welds in the problem area. No further fuel tank weld problems turned up then or subsequently. The two failures were thought to have been accelerated by low-level pressure/ vacuum cycling of the fuel tank, due to the approximately 1/2 psi (3.5 kPa) threshold for fuel delivery shut-off during fueling, and undesirable vacuum excursions caused by flow restriction of the spark arrestors at the tank atmospheric vent. The flow restriction has been addressed throughout the fleet by fitting 1/2-in. NPT spark arrestors rather than the 1/8-in. NPT devices originally specified. In addition, spark arrestors are now inspected periodically for cleanliness, to avoid flow restriction caused by plugging. As a further measure against future fuel tank weld failures, X-ray inspected fuel tank welds are specified for buses in LACMTA's latest procurement.

A fuel pressure sensor and low pressure indicator display is provided, which interrupts electric current to the fuel pump in the event of low fuel pressure. This feature guards against uncontrolled release of fuel, should a breach in the fuel system occur. Fuel circulating pumps in buses of the latest procurement feature an internal relief valve that prevents fuel pump damage or a fuel line rupture in the event of an excessive flow restriction or complete blockage.

Fuel filter system design has been improved in the buses of latest procurement from the standpoint of workers' potential exposure to methanol. A filter canister drain is provided to allow controlled emptying of an installed filter before removal. Upstream and downstream shut-off valves are also provided to minimize the volume of fuel that potentially could be spilled while the filters are being serviced.

As a result of a minor engine bay fire caused by a cracked fuel fitting, fittings like the one that cracked have been replaced with their stainless steel equivalent on all methanol buses.

Methanol Exposure

Fueling personnel wear long-sleeved, white overalls, eye shields, safety shoes, and gloves for both diesel and methanol fueling. Areas where methanol fuel is handled were tested for methanol vapor concentrations and were found to be well below regulated levels. Additional testing is done at the scene of any incident, such as a fuel spill. LACMTA's experience has led to the use of methanol-compatible (i.e., neoprene) gloves and improvement of fuel filter changing procedures to minimize the risk of methanol exposure.

PIERCE TRANSIT, WASHINGTON-CNG

Pierce Transit began using CNG powered buses in 1986 with two bi-fuel buses. They have become a large-scale user of CNG fuel in transit service, with 30 full-size and 19 paratransit service buses, a significant proportion of their total fleet, powered by CNG. CNG has been integrated into Pierce Transit's routine operations with a high level of safety, reflecting the planning and care taken for its use. The following paragraphs detail particular measures for the safe use of CNG taken by Pierce Transit since opting for CNG as an alternative fuel.

Safety Codes

Pierce Transit referred to NFPA 52 as the code for construction of their CNG refueling facility. In their CNG vehicle procurements, they specified that buses were to meet "all applicable state and federal codes."

Facility Modifications

Overhead safety harnesses were installed to protect workers from falling during any service involving the roof-mounted CNG tanks of Pierce Transit's full-sized CNG buses.

Pierce Transit determined that no fire safety modifications were required in their indoor facilities to accommodate CNG buses, as there was no code covering this situation, and natural gas was already present as a fuel for building heat. Existing fire protection measures, including smoke detectors, heat detectors, fire doors, fire alarms, sprinklers, fire extinguishers, fire blankets, an annunciator panel, and automatic notification of the fire department, were considered adequate.

Notwithstanding this one example, specific measures for indoor fire protection with CNG vehicles are strongly recommended. A letter from FTA to transit agencies expressing this viewpoint appears in Appendix
A. Pierce Transit plans to address this issue in the near future, by studying recommended practice and adopting suitable measures (such as methane detectors and ventilation upgrades) for their facility.

Safety Training

Safety training for CNG at Pierce County consists of classes for mechanics given by the bus manufacturer, the engine manufacturer, and Washington Natural Gas. Participants receive technical manuals from the bus manufacturer and safety handouts from Washington Natural Gas. All personnel are shown a CNG cylinder ruggedness video, which depicts composite-wrapped aluminum CNG cylinders in a series of potentially destructive tests. The intent of this video is to ease apprehensions some personnel may have about the highly pressurized gas cylinders. Scenes in the video depict various extreme conditions imposed on the cylinder, during which a flash of fire occurred when the lead plugs melted out of the cylinder in the blaze, but was subsequently extinguished by the force of gas escaping. The escaping gas did not ignite.

Refueling Station

CNG bus refueling at Pierce Transit is done just outside of the covered area provided for diesel bus refueling. Two dispensers are in lanes that continue from the diesel refueling lanes, and a third dispenser is located to one side for light duty vehicle refueling (Figure 6). Two large compressors provide CNG to the dispensers via six ASME pressure vessels (Figure 7). Sherex and Hansen refueling connectors are used, which mechanically lock onto the vehicle refueling receptacle (Figure 8). Their design prevents gas from flowing through the valve unless the device is properly connected. Dispensers are equipped with safety break-away fittings, which are designed to come apart before any other component fails, in the event of vehicle roll-away while the refueling connector is attached. Located in a nearby control room is an on-line CNG station status monitor supplied by the CNG station installer. The status monitor gives an attendant information about CNG station functions and status, showing, for example, whether any valve is open or closed, and displaying pressures at various points in the system (Figure 9). Pierce Transit has kept its original small CNG compressor station in commission for use as a back-up to the main compressors.

On-Board Fire Suppression

Pierce Transit's full-size Orion buses were equipped by the manufacturer with fire suppression systems, although this was not called for in the vehicle procurement. The system will detect excessive high temperature or actual fire in the engine compartment. When excessive temperature or fire is detected, a dry chemical fire suppression agent deploys, an alarm sounds, and a fire indicator on the instrument panel lights. After 30 seconds, the

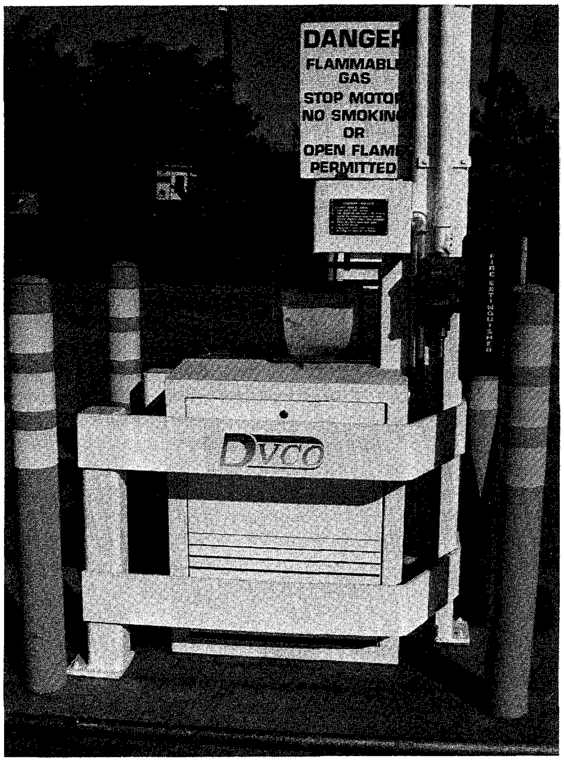

FIGURE 6 CNG Dispenser.

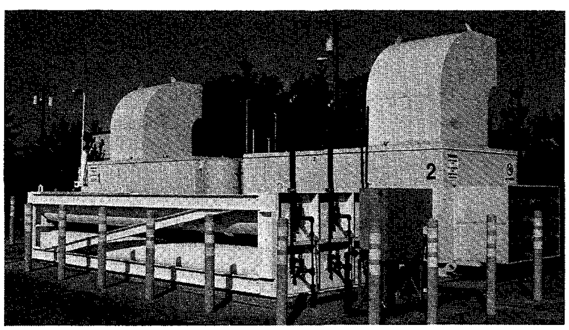

FIGURE 7 CNG Compressor and cascade.

engine is automatically disabled. Engine shutdown can be delayed by the operator, 30 seconds at a time, as required to bring the vehicle safely out of traffic. Once the engine is stopped, it may be restarted after a 30-second delay.

On-Board Fuel Systems

Pierce Transit has no operational issues with their vehicle fuel systems, which are installed by either the vehicle manufacturer, in the case of their full-size buses, or the vehicle converter, in the case of their paratransit buses. Early in their experience, a poorly running engine led to a catalytic converter fire. The engine stalled, but fuel flow continued and sustained the fire until personnel took action. As a result, vehicles are now equipped with a circuit that disables fuel flow when the engine is stopped.

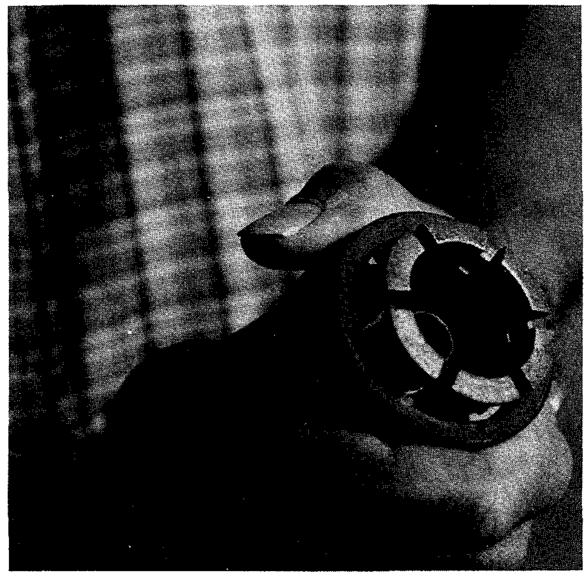

FIGURE 8 Sherex connector--open.

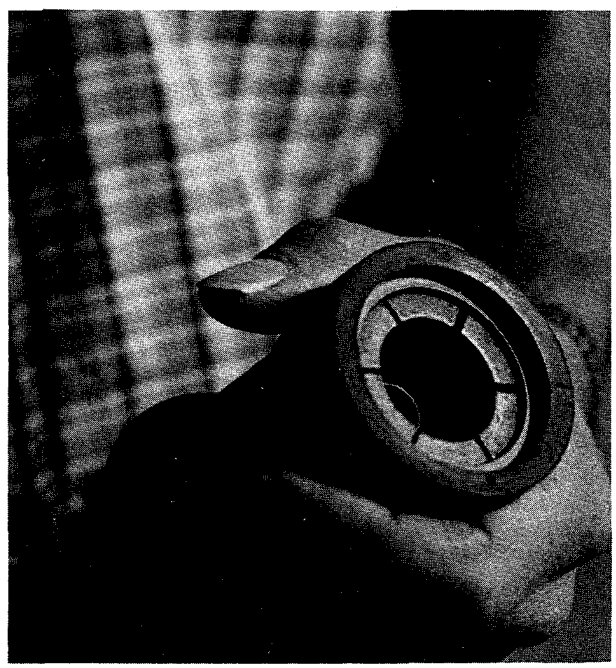

FIGURE 8a Sherex connector--locked.

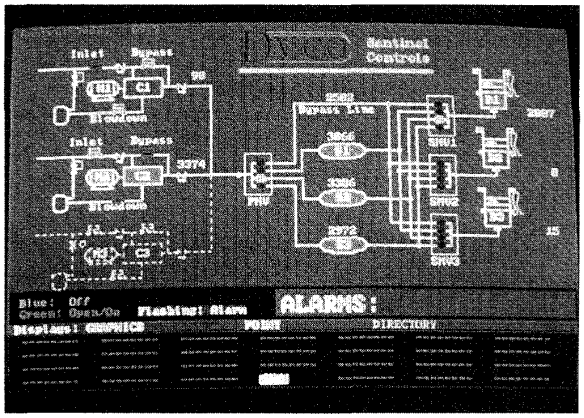

FIGURE 9 CNG Station display status.

METROPOLITAN TRANSIT AUTHORITY OF HARRIS COUNTY TEXAS (HOUSTON METRO)--LNG

In 1990, in response to a state mandate (Section 114.11 of the Texas Regulation IV of the Texas Natural Resource Conservation Commission, Control of Air Pollution from Motor Vehicles) requiring municipal authorities to purchase or lease only natural gas fueled vehicles, the Harris County MTA, known as Houston Metro, began the process of converting its transit fleet to LNG. At the end of 1993, 334 LNG fueled buses have been purchased by Houston Metro. Safety with this unfamiliar fuel has been given careful attention by Houston Metro as it is phased into operation.

Safety Codes

Houston Metro found few codes applicable to LNG in a transit operation. Their approach was to follow Texas Railroad Commission and FMVSS regulations as closely as possible for vehicle fuel systems. Texas Railroad Commission regulations were also used as a guide for construction of LNG fuel stations. Adherence to Houston's city fire codes and input from the fire marshall throughout the planning stages were key to gaining approval of Houston Metro's LNG facilities. The transit authority's fire insurance carrier provided consultation and advocacy during the approval process.

Facility Modifications

Specific facility modifications were not required at Houston Metro to begin integrating LNG into their bus operations. Houston Metro has subsequently made a business decision to upgrade fire prevention design of their maintenance facilities to include methane detectors, increased ventilation in response to methane detection, and explosion-proof heating and other equipment.

Safety Training

Safety training is given to operators, mechanics, and cleaner/fuelers. Operator training consists of a 4-hour classroom session. Mechanics undergo a four step program, from introduction to technical training. Cleaner/fuelers receive an introductory class and hands-on training. Safety handouts developed by Houston Metro are provided to training recipients. In addition, an on-going series of "Technical Bulletins" is distributed, covering detailed service and safety topics. Many employees were trained in the Texas Railroad Commission's safety program for compressed natural gas.

The one serious accident that has occurred with LNG at Houston happened when "an outside vendor employee violated established safety procedures and circumvented safety features." A bus undergoing maintenance by an outside worker self-detected an LNG leak. The individual, wishing to remove the bus from the building, defeated the engine disablement function of the on-board safety system, and started the bus. A fire resulted, doing significant damage to the interior of the bus. This incident serves to emphasize the importance of proper training and supervision. Two minor fires have occurred, both during removal of the mixer from the Ford 7.5 liter engine. New procedures were established, requiring a cooldown period before removal of the mixer. This development points out the learning curve that occurs with any new technology, and shows how procedures can be defined to alleviate a hazard. Houston Metro uses a training trailer, which is essentially a bus shell showing the engine and the fuel delivery system.

Refueling Stations

LNG fueling is currently done at three Houston Metro bus maintenance facilities, and three additional LNG fuel stations are in conceptual engineering or design stage. The existing LNG stations are located outdoors, completely separated from diesel fueling and other activities (Figure 10). Future LNG stations will be integrated into existing diesel fuel lanes. Single and multiple 10,000 gallon (35 500 liter) upright supply tanks are used, situated in containment enclosures (Figure 11), which also provide a containment sump. Pipes to and from the supply tanks are clearly labeled.

A control and status panel provides needed functions during replenishment of these tanks. Infrared heat detectors, alarms, and automatic fire suppression are installed for protection in the event of fire.

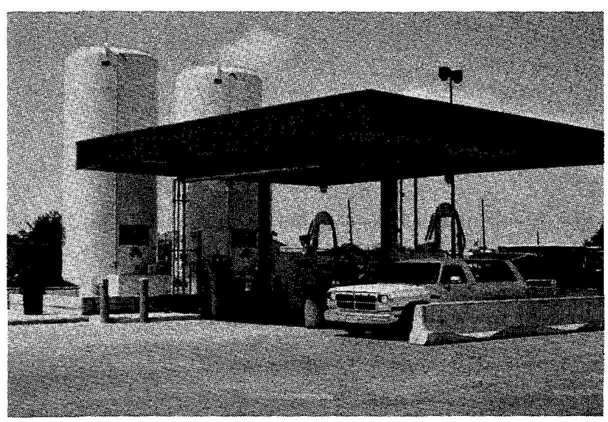

FIGURE 10 West LNG station.

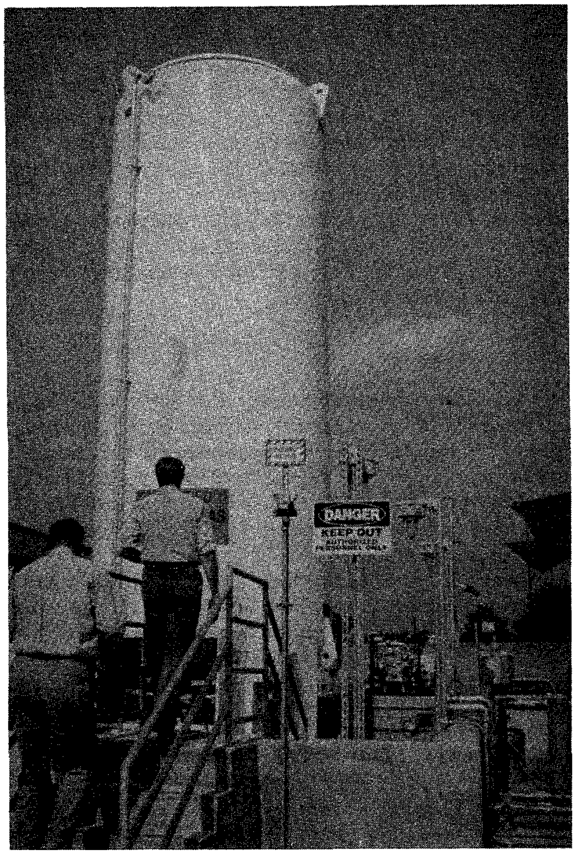

FIGURE 11 LNG Containment pit.

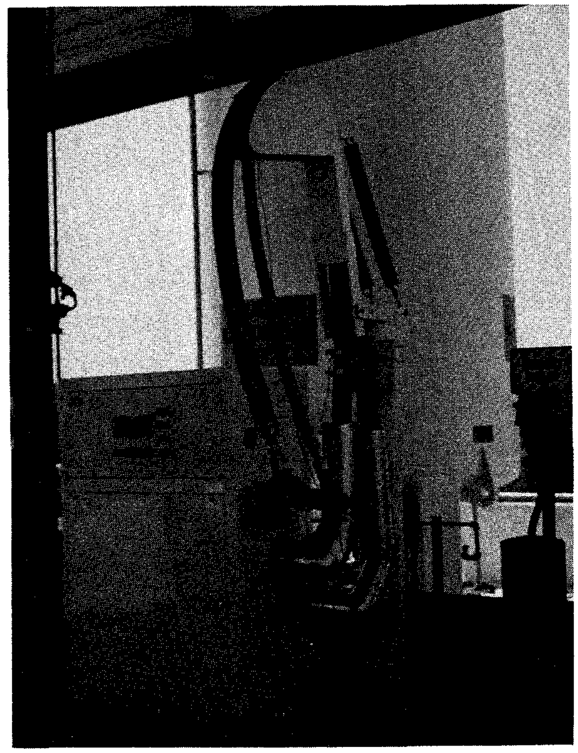

FIGURE 12 LNG Dispenser.

LNG dispensers outwardly resemble other fuel dispensers (Figure 12). Operation is via pushbuttons and a display mounted on the dispenser. An emergency shut-off is mounted near the dispenser next to the station status panel.

Numerous cryogenic nozzle designs by several manufacturers were tried and abandoned before adoption of the current nozzle (Figure 13). Leakage, freezing, and wear were problem areas in the early nozzles tried at Houston Metro. The current nozzle design is based on a cryogenic nozzle for military applications, with improvements stemming from Houston Metro's experience and specifications. Further improvements are being sought in this design. Separate liquid and vapor recovery connections are used for a fueling transaction (Figure 14). Use of the vapor recovery hose is optional, depending on the on-board fuel pressure and amount of fuel required. When vapor recovery is employed, vapor is returned to the supply tank.

Mandatory protective gear for fuelers during fueling consists of a full face shield (incorporating tight-fitting goggles), full-length gloves, and a full-length apron (Figure 15). Houston Metro has 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.

FIGURE 13 Parker LNG nozzle.

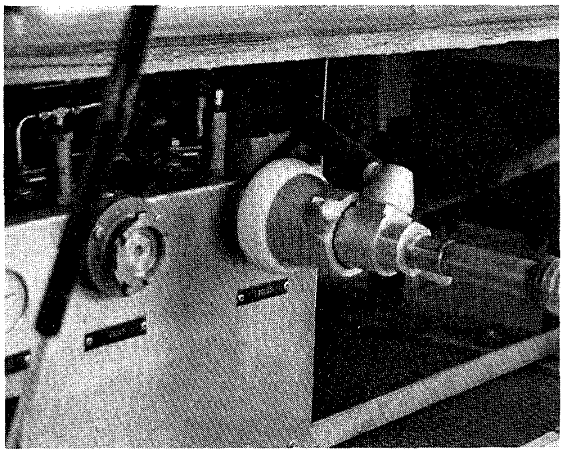

FIGURE 14 Fueling nozzle connected to bus.

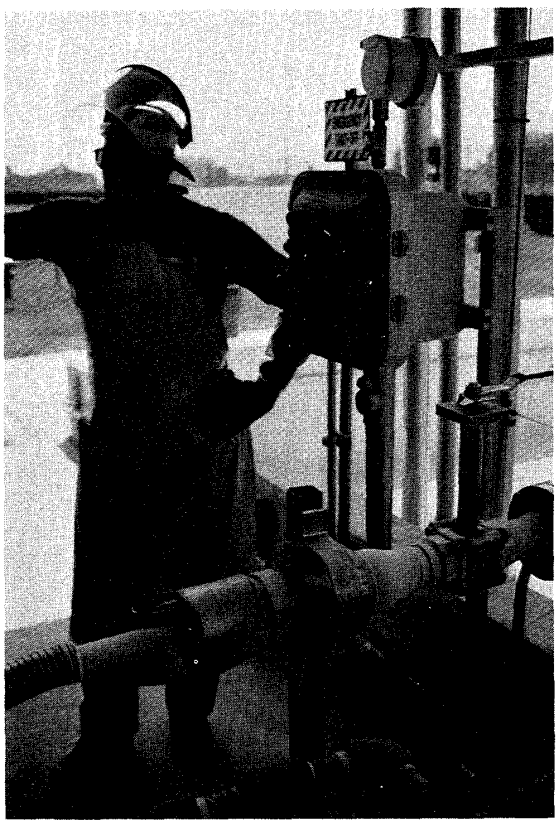

FIGURE 15 Protective equipment.

On-Board Fire Prevention and Suppression

LNG is odorant-free, so buses are equipped with methane detection systems. The systems operate 24 hours per day. Leaks are indicated to the operator as "trace," "significant," or "critical" accordingly as the concentration of methane detected reaches 15 percent, 30 percent, and 45 percent respectively, of the lower ignition level. If a leak is detected while a vehicle is parked, the system automatically activates the vehicle horn and flashes the lights. The system will initiate an engine shutdown sequence if a critical leak is detected while the vehicle is being operated. The operator may temporarily override engine shutdown a maximum of two times, should the situation warrant.

Buses are also equipped with a fire suppression system, consisting of heat detectors, operator indicators, and fire extinguishers. The fire extinguishers are deployed if fire is detected in the engine compartment or undercarriage areas.

On-Board Fuel System

Houston Metro has found that cryogenic fuel systems are especially susceptible to leaking at the joints, caused by temperature cycling and thermal expansion. Welds are preferred when feasible. Stainless steel compression fittings have also proven reliable. Tapered fittings requiring thread sealant have been problematic, with no type of thread sealant tried so far proving completely satisfactory (Figure 16).

On-board fuel systems are different from those for other fuels. A key safety element is a pressure relief valve that allows venting of vapor should the design pressure of the storage tank be reached. This should not occur in normal operation, as pressure rise in the tank resulting from heat transfer is offset by consumption of fuel. However, if the bus were parked for an extended period (beyond 8 days), pressure could rise to the point where venting occurs.

ORANGE COUNTY TRANSPORTATION AUTHORITY, CALIFORNIA--LPG

Orange County Transportation Authority (OCTA) has been using LPG in paratransit buses since 1980. In 1990, two full-size

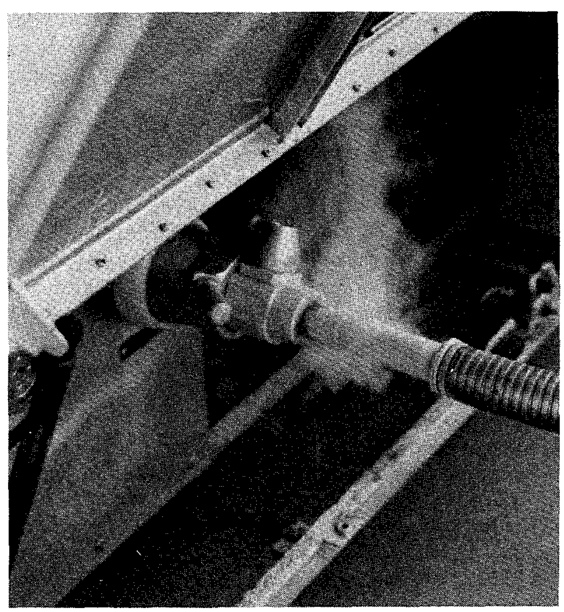

FIGURE 16 LNG leak at tapered fitting.

LPG buses entered service as part of a six-bus clean fuel experiment that also included two methanol and two CNG buses. OCTA began testing a third full-size LPG bus in 1992, and has plans to convert two more to LPG in the near future. Meanwhile, OCTA's paratransit LPG fleet has grown to 172 buses, making OCTA a large-scale LPG user. Attention was paid to safety from the outset, and no LPG related accidents have occurred.

Safety Codes

OCTA followed NFPA 58 in configuring buses for LPG fuel, as did the LPG supplier in construction of the LPG refueling station.

Facility Modifications

OCTA has made no facility modifications to accommodate LPG or other alternative fuels, choosing instead to perform maintenance on their large LPG buses outdoors. Paratransit buses are maintained indoors. The existing fire safety equipment includes sprinklers and hand-held fire extinguishers. The facilities where LPG paratransit buses are maintained are staffed 24 hours a day; the means of fire detection at these facilities is visual. Alarms are relayed to a communications panel in the supervisor's office. The fire department is notified by telephone.

Safety Training

Operators and mechanics receive LPG safety classes based on material prepared by a consultant to OCTA. In addition to handouts prepared by the consultant, participants receive a booklet entitled "Propane Safety" *(27),* provided by the LPG supplier.

Refueling Stations

OCTA's LPG refueling stations, tanks, pumps, and equipment are furnished by the LPG supplier and OCTA provides funding for installation. At OCTA's request, the supplier also provided a larger supply tank to support increased use. LPG stations are located outdoors and away from other activities (Figure 17). Separate dispensers are located at opposite ends of the supply tank. One dispenser serves transit and paratransit buses, and is equipped with a large, high-volume fueling connector (Figure 18), while the other dispenser serves support vehicles, and is equipped with a

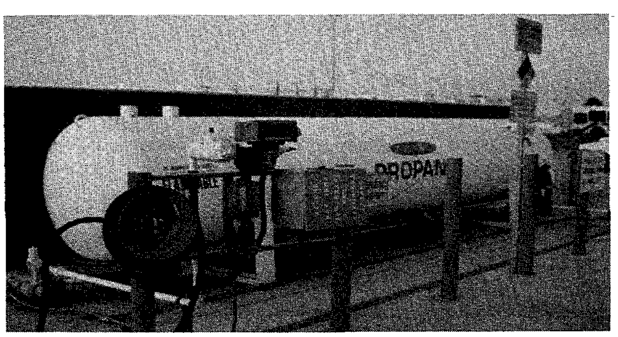

FIGURE 17 LPG station.

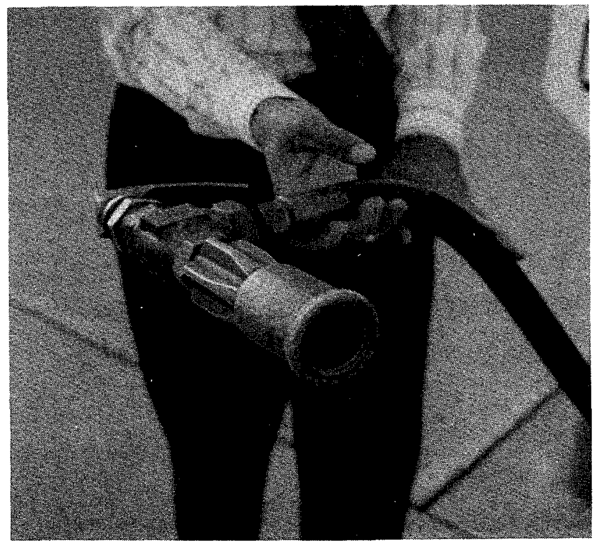

FIGURE 18 High-volume fueling connector.

standard automotive fueling connector. Safety face shields and gloves, an emergency shut-off, and a fire extinguisher are provided near the dispensers.

On-board Fire Suppression

OCTA's full-size LPG buses are equipped with fire suppression systems in the engine compartment and fuel bay. The system will immediately deploy halon fire extinguishers when a fire is detected in either area. If the fire is in the fuel bay, dry chemical fire extinguishers are also immediately deployed. In either case, a warning light and a buzzer are activated at the operator's station. If the fire is in the engine compartment, a 10-second engine shutdown sequence begins. After 10 seconds, the engine is automatically shut off. If the fire is in the engine bay, a dry chemical fire extinguishing agent is deployed at this time.

On-board Fuel Systems

Fuel systems on OCTA's LPG buses are designed according to standard automotive LPG practice. Pressure relief valves are provided to protect against over-pressure at several points in the system. An inlet check valve prevents fuel from exiting at the fill point. A manual shut-off valve is provided for servicing and emergency shut-off. The fuel receptacle of a full-size bus is shown in Figure 19.

GREATER PEORIA MASS TRANSIT DISTRICT, ILLINOIS--ETHANOL

GP Transit began using ethanol buses in 1992. With 14 mono-fueled ethanol buses, they are the largest U.S. user of Office of Energy Maintenance (OEM)-manufactured dedicated ethanol

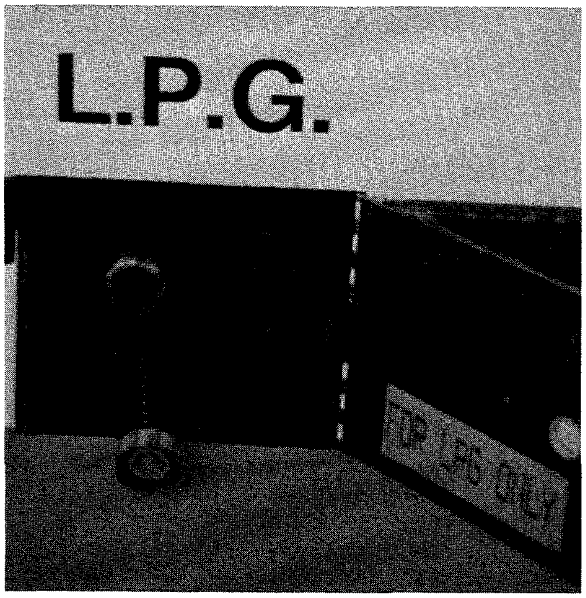

FIGURE 19 Bus LPG receptacle.

buses. Appropriate procedural and equipment modifications have been implemented for ethanol, and no significant safety incidents have occurred in their relatively brief experience.

Safety Codes

Information about specific fire and construction codes followed was not available from GP Transit, as these issues were dealt with by their building contractor on GP Transit's behalf.

Facility Modifications

GP Transit indicated that their maintenance building was constructed to accommodate ethanol fuel buses. Attention was paid to ventilation, to avoid possible problems with aldehyde fumes.

Safety Training

Safety training for ethanol fuel at GP Transit is given to operators, mechanics, and supervisors. Training is given by the engine manufacturer's representative, and consists of a classroom session with handouts. The instruction deals with handling ethanol fuel, vehicle operation, and emergency procedures.

Refueling Stations

E95 fuel (ethanol plus 5 percent unleaded gasoline) is used at GP Transit. The 5 percent gasoline acts as a denaturant to make the ethanol unpalatable and provides added flame luminosity. Ethanol dispensers have been added to existing fuel islands. Mechanically locking refueling connectors are used. The nozzles' design prevents fluid from being transferred unless the device is properly connected. During fueling, the bus is grounded to the dispenser by virtue of steel reinforcement in the dispenser hose. As a further precaution against a static electrical charge build-up and subsequent discharge during refueling, a redundant ground strap is connected to the fuel tank as the first step in the filling procedure. The dispensers are also equipped with safety break-away fittings, which are designed to break apart before any other component fails, in the event of vehicle roll-away while the nozzle is connected.

On-Board Fire Suppression

GP Transit ethanol buses are equipped with a fire detection and suppression system similar to that used by LACMTA. Heat sensors are located in the engine and fuel compartments. Activation of a heat detector results in automatic deployment of a halon fire extinguisher in the affected area. A tell-tale warning light and alarm are activated to notify the driver. No automatic engine shutdown is provided.

On-Board Fuel Systems

Ethanol bus fuel tanks incorporate several features that minimize the chance of spills, leaks, or ignition sources entering the vapor space of the tank. The mechanically locking fueling connectors incorporate poppet valves that remain closed until the nozzles are properly attached and locked in place. The fuel filler neck extends to the bottom of the tank, so that it is always immersed in liquid ethanol. A single atmospheric vent is provided, which is fitted with a stainless steel spark arrestor. A level control valve is provided which, during fuel dispensing, closes when the fuel reaches the desired level. The fuel delivery nozzle is equipped with a pressure sensor that shuts off the flow of fuel in response to the back pressure caused by the closed level control valve.

A fuel pressure sensor and low pressure indicator display is provided, which interrupts electric current to the fuel pump in the event of low fuel pressure. This feature guards against uncontrolled release of fuel, should a breach in the fuel system occur. Fuel circulating pumps feature an internal relief valve that prevents fuel pump damage or a fuel line rupture in the event of an excessive flow restriction or complete blockage.

Ethanol Exposure

GP transit has not reported problems with unauthorized use of ethanol. This is probably due to a combination of training, supervision, and the 5 percent gasoline denaturant present in GP Transit's E95 ethanol. Furthermore, the fueling nozzle design in use for ethanol at GP Transit does not lend itself to discharging fuel except when properly connected to an ethanol vehicle tank.

CHAPTER FIVE

A SUMMARY OF PRACTICE

A key element of this synthesis project was the survey of transit agencies that were experienced in using alternative fuels. A questionnaire, provided in Appendix B, was mailed to 28 transit agencies, located in all regions of the contiguous United States. A list of questionnaire recipients appears in Appendix C.

Of the 28 questionnaires issued, 17 were returned fully or partially completed. As expected, various transit agencies respond somewhat differently to the set of actual regulations, local requirements, and best-judgement approaches. Nevertheless, probably because methanol, LPG, and CNG have become well-known alternative fuels for transit, fuel handling and operational modifications for these fuels seem to be most consistent among the sites surveyed. Only one site provided information about its handling of LNG fuel, a newcomer to the transit arena, so the discussion of current practice for this fuel relies almost exclusively on the experiences of that single agency. Information from only one user of ethanol is included in this study. However, this agency is a representative example of future mainstream ethanol use with factory-built, emissions-certified, dedicated ethanol engines, as opposed to converted dual-fuel ethanol/diesel engines in use at some other sites. Because of the fuels' similarity, much of the methanol experience can be directly applied to ethanol.

Several trends surfaced from the information provided. For methanol and ethanol, most facilities did not undertake major facility modifications, aside from refueling facility installation. Many respondents employed fire protection systems on-board the methanol buses, and occasionally in service facilities. Operational constraints most often mentioned with methanol buses were reduced driving range, special refueling and maintenance procedures (most agencies performed refueling on-site), and increased downtime of buses. Most respondents took advantage of training sessions and materials provided to them by fuel suppliers or other participants.

Some CNG users made modifications to maintenance facilities, such as increasing ventilation and upgrading electrical equipment, although several CNG respondents made no special facility changes. Among the operational constraints named were slow refueling, reduced acceleration power, reduced range and payload, and increased downtime. CNG users reported that training sessions and materials were generally provided by fuel suppliers or other sources.

LPG respondents reported no modifications to facilities other than addition of refueling capability. Reduced range, new refueling procedures, and increased downtime were listed as operational constraints. Training sessions and materials were provided by fuel suppliers and consultants.

The LNG respondent initially made no facility modifications, but has since begun making some changes to ventilation and heating systems in maintenance buildings. Additional fueling requirements were noted as an operational constraint of LNG use in pilot-ignited diesel engines, and the agency currently has three refueling bases in its operating region. The agency has developed a four-part training course for mechanics, and LNG bus operators each participate in a 4-hour classroom training session.

The following material summarizes the results of questions 2 through 20 of the returned questionnaires. Question 1 asked for general information about the transit agencies, and is not summarized.

Outline of Alternate Fuel Projects (Questions 2, 3 & 4)

The responses to these questions give an outline of the agencies' alternative fuel efforts and are tabulated below.

Question 2. *Please list alternative fuels used in your fleet:*

Response	Number of Questionnaires with this response
Methanol	6
LNG	1
Ethanol	1
CNG	13
LPG (Propane)	2

Question 3. *Please indicate which of the following alternative fuel configurations are used in your fleet:*

Response	Number of Questionnaires with this response
Dedicated 100% Alternative Fuel	16
Pilot Ignition Diesel	5
Flexible Fuel (mixture of gasoline and alcohols)	2

Question 4. *For each alternative fuel chassis/engine combination in your fleet, please indicate: Chassis (Mfr., Model, Year):*

Response	Total indicated by Questionnaires
GMC/TMC (All models)	376
Neoplan (All models)	101
Flxible (All models)	53
Gillig Phantom 1989	6
BIA/Orion (All models)	32
Ikarus	60
Eldorado National (All models)	26
Mercedes	7
Ford E Series (All models)	172
Ferroni	74
All others	18

Bus Length:

Response	Total indicated by Questionnaires
60' (18m)	33
45' (14m)	60
40' (12m)	513
35' (10.6m)	20
Less than 30'(9m)	288

Engine (Mfr., Model, Year):

Response	Total indicated by Questionnaires
DDC 6V-92 (All models)	661
Cummins L-10 (All models)	87
Ford 7.5 liter (All models)	190
All Others	8

Incidents and Accidents (Question 5)

Respondents were asked to describe any incidents or accidents involving alternative fuel at their agency, and to note any measures taken to minimize a recurrence. Only limited response to this item was provided, other than by the agencies in the Case Studies (see previous section). It may be that some agencies were sensitive about reporting such incidents.

Rules, Codes and Regulations (Question 6)

The agencies were asked to list the applicable rules, codes, and regulations for the alternative fuels used at their operations. The responses are summarized in the following table.

Response	Number of Responses
NFPA (All codes)	10
CGA (All codes)	2
DOT (All codes)	3
SAE (All codes)	1
ASME	1
UL	1
FVMSS	5
State & Local Codes/Guides/ Permits	9
FTA Training Manuals	3
Manufacturer Recommendations	4
Utility Recommendations	1
Internally Developed Guidelines	2

Facility Modifications (Question 7)

Modifications reported by questionnaire respondents include increased ventilation, methane detectors/alarms, upgrade of space to explosion-proof maintenance room, and halon fire extinguishing.

Operational Constraints (Question 8)

Typical questionnaire responses listed reduced range, new refueling procedures, new maintenance procedures, slow fueling, refueling equipment problems, low power, reduced payload, increased downtime, and new lubricants as operational constraints.

Relocation of Activities (Question 9)

Most questionnaires responding for CNG reported relocation of fueling to an outside, uncovered location. Many also reported relocation of bus maintenance, inspection, and parking to the outdoors. Some questionnaire respondents reported fueling at an outside vendor or locating their own methanol facility separately from their existing fuel stations. Many respondents reported integrating the alternative fuel into their existing fueling locations. According to questionnaire responses, maintenance and other activities generally remained at the usual location.

Safety Program (Question 10)

Questionnaire respondents indicated that training sessions and materials were provided by fuel suppliers, equipment suppliers, consultants, the USDOT, local fire department, and in-house sources. Useful training documents cited include the UMTA (now FTA) *Training Manual For Methanol Fuel Use in Transit Operations (13),* the *U.S. DOT Compressed Natural Gas Fuel Use Training Manual (28),* and *Propane Safety (34).*

Refueling (Questions 11 & 12)

Methanol & Ethanol

Methanol and ethanol refueling is generally done on-site. The Emco-Wheaton Posi-Lock nozzle for methanol fueling was indicated as the nozzle used by all questionnaire respondents using methanol or ethanol. Flowrates listed were 22-50 gallons per minute (gpm) (80-180 I/min). Storage tanks listed were 5,000-50,000 gallons (18 000-180 000 liters). Tank constructions listed were steel, Plasteel, Convault, and double-wall fiberglass. Aboveground and underground tanks are used. Chemical supply companies were the fuel suppliers listed by questionnaire respondents using methanol and ethanol.

Questionnaire respondents using methanol and ethanol listed a few problems with refueling, such as supply interruptions, dispenser problems, and nozzle failures.

LNG

LNG fueling nozzles used are Parker and Moog mechanically locking units, with vapor return. Flowrates are 8 to 40 gpm (30150 I/min). Typical storage is in permanent 10,000 gallon aboveground vertical stainless steel insulated tanks, and in 10,000 gallon (36 500 liter) trailer-mounted tanks of the same construction. LNG is supplied to Houston Metro by Liquid Carbonic.

Nozzle leakage, nozzle seal difficulties, and pump problems are concerns that Houston Metro has had to deal with at their refueling facilities.

CNG

CNG refueling is generally done on-site. Nozzles listed by questionnaire respondents are Hanson, NGV-1, Sherex 1000, Sherex 5000, Parker-Hannefin, and Foster MFG H2. Flowrates listed are 20-900 standard cubic feet per minute (scfm) (0.6-25 m^3/min). Typical storage tanks are above-ground ASME or DOT steel pressure vessels. Storage capacities listed are 25,000-75,000 scf (700-2100 m^3), at up to 5,000 psi (35 MPa). Maximum cascade operating pressures listed are 3,000-4,300 psi (20-30 MPa). Compressor capacities listed are 20-3,200 scfm (0.6-90 m^3/min). Natural gas is provided by the local gas utilities.

Refueling problems, such as slow fueling, nozzle failures, compressor failures, and oil contamination were reported by questionnaire respondents using CNG.

LPG

LPG refueling is done on-site by the respondents. Nozzle types were not specified. One respondent indicated a flowrate of 20 gpm (75 I/min). Tank capacities are 800-3,000 gallons (3000-11 000 liters). Tank construction is steel, above ground. Fuel suppliers are local LPG distributors.

The only LPG refueling problem uncovered in the questionnaires was an improperly calibrated meter.

Maturity of Alternative Fuel Industry (Question 13)

Several questionnaire respondents indicated that there was room for improvement in availability, applicability, or clarity of construction and safety codes, standards, or guidelines. Many respondents indicated that they had no problems in these areas. A similar mix of experiences was indicated regarding availability and performance of contractors and equipment.

Factors Prompting Use of Alternative Fuels (Question 14)

Several factors were listed by questionnaire respondents as inducements to use alternative fuel. Ranked by frequency of mention, they are listed below.

- Air quality benefits
- Compliance with legislation
- Opportunity to purchase new buses
- Good corporate citizenship
- Domestic fuel supply
- Safety
- Operating cost savings
- Involvement with new technology

Initial View of Alternative Fuels (Question 15)

Comments received on returned questionnaires indicated a spectrum of outlook by the transit agencies when they initially began using alternative fuels, from apprehension, skepticism, and caution ranging to welcoming the challenge, and even enthusiasm.

Experienced View of Alternative Fuels (Question 16)

Many respondents expressed disappointment with their experiences with alternative fuels resulting from technical problems, high costs, and lack of industry maturity. Several respondents indicated that they remained optimistic that the problems would be solved. Some respondents even indicated that their experience had been positive, and that they believe that implementation of alternative fuels should continue.

Non-Environmental Benefits of Alternative Fuels (Question 17)

A number of expected or realized non-environmental benefits of alternative fuels were mentioned by the questionnaire respondents and are listed below.

- Enhanced public image
- Increased engine life due to cleaner combustion
- Good corporate experience
- Marketable emissions credits
- Reduced fuel cost
- Reduced maintenance cost
- Better appreciation for conventional fuels
- Reduced on-site fuel inventory (CNG)
- Stabilization of the corn market (ethanol)

Disadvantages of Alternative Fuels in Daily Use (Question 18)

Some of the disadvantages of alternative fuels in daily use indicated by the questionnaire respondents were, by frequency mentioned:

- Higher costs
- Increased complexity or problems
- Increased downtime or roadcalls
- Poor range
- Limited fuel suppliers or supply interruptions
- Longer fueling time
- Lower efficiency
- Off-site fueling
- Reduced payload

Issues To Be Addressed (Question 19)

Questionnaire respondents were asked to indicate the problems or difficulties with alternate fuels that they thought should be addressed in the future. The responses were, by frequency mentioned:

- Durability and reliability
- Efficiency and cost
- Training
- Quality of equipment
- Standardization of equipment
- Fueling time and complexity

- Fuel storage
- Infrastructure
- Fuel composition (CNG)
- Codes, standards, and guidelines
- Availability of information
- Diagnostics
- Safety

Comments and Anecdotes (Question 20)

Questionnaire respondents were asked to provide any relevant comments or anecdotes that were not uncovered elsewhere in the questionnaire. Remarks were provided by a few of the agencies.

Greater Peoria Mass Transit District (Ethanol/DDC 6V-92/1992 TMC RTS 06)

"Most problems we have experienced have been relatively minor compared to what we had anticipated could happen. We have been pleasantly surprised to enjoy such reliability."

Los Angeles County Metropolitan Transportation Authority (Methanol/DDC 6V-92/1989, 1992 TMC RTS; CNG/Cummins L-10/1990 Flxible Metro)

Because alternative fuels are new to many people they tend to think worst case for all things. Education and hands-on training is very important."

Transit Management of Tucson, Inc. (CNG/DDC 6V-71 conversion/1973 GMC 4253; CNG/DDC 6V-92 conversion/l991 Neoplan AN440; CNG/V-8 conversion/1982 Boyertown Trolley)

"U.S. DOT should provide more funding assistance for the systems willing to aggressively pursue alternative fuel technologies."

Metro-Dade Transit Agency (CNG/Cummins L-10/1990, 1992 Flxible Metro; Methanol/DDC 6V-92/1992 Flxible Metro)

"Alternative fuel vehicles will be a practical choice but, like with any infant industry, there will be growing pains."

CHAPTER SIX

CONCLUSIONS AND GENERAL RECOMMENDATIONS FOR FURTHER RESEARCH

The level of activity of transit agencies using the alternative fuels covered in this synthesis indicates that these fuels are being seriously considered as potential long-term contributors to the alleviation of air pollution and energy security concerns.

Many technical, logistic, and safety issues are being dealt with by the transit agencies using alternative fuels. Some of these issues are nearing resolution.

Each of the fuels studied has characteristics that require different, and more rigorous safety precautions and practices than those required for diesel fuel. The information compiled in this project leads to the following general conclusions about the status and future development of safe operating procedures for methanol, ethanol, CNG, LNG, and LPG.

CONCLUSIONS

Methanol

- Technical issues of methanol fuel in transit operations are well understood and approaching solution. Engine and fuel system reliability are nearing desired levels. Low emissions of methanol engines allow transit agencies to meet regulatory mandates and local air quality goals. Domestic resources exist to supply a large national methanol vehicle fleet. Under current market conditions, the cost of methanol is substantially higher than diesel on an energy equivalent basis.
- Safe methods of using methanol fuel have been developed and the safety record of transit agencies using methanol has been good.
- Regarding methanol's low flame luminosity and high toxicity, training, proper equipment, and on-going vigilance are required to prevent these concerns from becoming hazards.

Ethanol

- Technical issues of ethanol fuel in transit operations are understood and approaching resolution. Engine and fuel system reliability are near desired levels. Emission levels of ethanol engines meet regulatory mandates and local air quality goals. The domestic agricultural sector's ability to support a large national ethanol vehicle fleet is problematic, because fuel ethanol is essentially a grain by-product in today's market. The growing of crops specifically for ethanol production would have a major impact on the whole agricultural sector. Under current market conditions, the cost of ethanol is substantially higher than diesel on an energy equivalent basis.
- Safe use of ethanol fuel is practiced by transit agencies, and this is reflected in their safety records.
- Training, proper equipment, and on-going vigilance are required to prevent ethanol's low flame luminosity from becoming a hazard. While toxicity of ethanol is not as acute as that of methanol, the temptation for abuse exists, and must be discouraged.

Compressed Natural Gas

- CNG transit vehicles are at a disadvantage with respect to range and payload. As yet uncertified all-composite CNG onboard tank technology can reduce the payload disadvantage by about one-half. Range of CNG vehicles, even though less than with other fuels, is suitable for many transit routes. Engine and fuel system reliabilities are approaching desired levels. The industry is still dealing with the issue of natural gas composition. Low emissions of natural gas engines allow transit agencies to meet regulatory mandates and local air quality goals. Domestic resources exist to supply a large national CNG vehicle fleet. Under current market conditions, the cost of CNG is similar to that of diesel on an energy equivalent basis.
- Safe use of CNG is well understood by its users, and the safety record of transit agencies using CNG has been good.
- Existing bus facilities are configured for safe dissipation of heavier-than-air fuel vapors. The tendency of leaked natural gas to rise requires redesign of a facility to accommodate CNG vehicles. Improved ventilation and elimination of ignition sources near the ceiling are the design goals for conversion of a facility for CNG vehicle use.

Liquefied Natural Gas (LNG)

- From the Houston experiences it appears that LNG combines the low operating cost of natural gas with the on-board storage density of a liquid fuel. Engine and fuel system reliabilities are approaching desired levels. Technical issues of handling the cryogenic liquid are challenging, but are being resolved. Low emissions of natural gas engines allow transit agencies to meet regulatory mandates and local air quality goals. Domestic resources exist to supply a large national LNG vehicle fleet. Under current market conditions, the cost of LNG is similar to that of diesel on an energy equivalent basis.
- Safe use of LNG is being pioneered at transit agencies such as Houston Metro. The safety record at Houston Metro has been good.
- Avoidance of and response to cryogenic injuries are new disciplines that must be learned where LNG is to be used.
- Existing bus facilities are configured for safe dissipation of heavier-than-air fuel vapors. The tendency of leaked natural gas to rise requires redesign of a facility for LNG vehicles. Improved ventilation and elimination of ignition sources near the ceiling are the design goals for conversion of a facility for LNG vehicle use. Because odorization of LNG is not thought to be practical, methane detectors must be used for detection of invisible, inaudible leaks.

Liquefied Petroleum Gas (LPG)

- Technical issues of LPG fuel in transit operations are basically solved. Engine and fuel system reliability are approaching desired levels. Potential low emissions of LPG engines allow transit agencies to meet regulatory mandates and local air quality goals. LPG combines the low operating cost of a refinery by-product with the on-board storage density of a liquid fuel. Because LPG is a petroleum product, and is currently a net import to the United States, increased use of LPG in transportation does not advance the country's energy security. Under current market conditions, the cost of LPG is similar to that of diesel on an energy equivalent basis.

- The safety record of transit agencies using LPG has been good, indicating consistent use of safe practice.
- While most of LPG's characteristics are similar to those of gasoline, its storage under pressure poses an added concern. Awareness, training, and proper equipment can prevent this concern from becoming a hazard.

RECOMMENDATIONS FOR FURTHER RESEARCH

Much useful information was gathered in this study. A review of the information revealed some diversity among the transit agencies surveyed in the following areas:

- The scale of their alternative fuel projects,
- The size of their alternative fuel buses,
- The environmental and safety codes adhered to, and
- The way they interpret these codes.

The findings of this study must be read with this diversity in mind.

Building on this information, an interesting topic for further research would be a study of different alternative fuels in large-scale use at a single transit agency. The opportunity for such a study does not currently exist, but will likely occur in the near future. Another interesting topic for further research would be a follow-up study to track the progress of the alternative fuel projects, and reveal resolution of some of the issues.

Other research topics have been suggested. They include:

Methanol Topics

- Flame Luminosity

CNG Topics

- Tanks
- Refueling (fast-fill heating effect)
- Storage via adsorption

LNG Topics

- Storage/Handling
- Fuel Delivery Systems
- Vapor Handling (vapor return, reliquefication)
- Odorization
- Standards

General Topics

- Infrastructure
- Energy Security
- Safety Comparison
- Cost Comparison (Total, Operating, Conversion)
- Viability
- Future Fuels and Propulsion Systems (e.g., Hythane, Solar Energy)
- Transit Facility Design

LIST OF ABBREVIATIONS AND ACRONYMS

ACGIH	American Council of Governmental Industrial Hygienists
ASME	American Society of Mechanical Engineers
BIA	Bus Industries of America
CAAA	Clean Air Act
CARB	California Air Resources Board
CGA	Canadian Gas Association
CNG	Compressed natural gas
DDC	Detroit Diesel Corporation
DOT	U.S. Department of Transportation
E85	85 percent ethanol/15 percent unleaded gasoline fuel
E95	95 percent ethanol/5 percent unleaded gasoline fuel
EPA	U.S. Environmental Protection Agency
FTA	Federal Transit Administration
FMVSS	Federal Motor Vehicle Safety Standards
LACMTA	Los Angeles County Metropolitan Transportation Authority
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
M100	Neat methanol
M85	85 percent methanol/15 percent unleaded gasoline fuel
NESCAUM	Northeast States for Coordinated Air Use Management
NFPA	National Fire Prevention Association
NIOSH	National Institute for Occupational Safety and Health
NPT	National Pipe Thread
OCTA	Orange County Transportation Authority/Orange County Transit District
OSHA	Occupational Safety and Health Administration
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
SMAQMD	Sacramento Metropolitan Air Quality Management District
SRTD	Sacramento Regional Transit District
TIS	Technical Information Services
TRB	Transportation Research Board
TRIS	Transportation Research Information System
UFC	Uniform Fire Code
UMTA	Urban Mass Transportation Administration (now FTA)

Amendments of 1990

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APPENDIX A
FTA LETTER TO TRANSIT AGENCIES

US Department of Transportation

The Administrator

400 Seventh St SW
Washington, DC ??
C-93-12

Federal Transit Administration

NOV 10 1993

Dear Colleague:

Numerous transit agencies are introducing or planning to introduce alternative fueled vehicles into their operations. The Federal Transit Administration (FTA) supports these efforts to improve air quality and reduce national dependence on petroleum-based fuels.

As part of the FTA program, surveys have been conducted of alternative fuel operations at a number of transit bus facilities. The physical and chemical characteristics of alcohol, gaseous, and cryogenic fuels are significantly different from those of diesel. Appropriate safety precautions associated with their use must be considered carefully to assure safe operations.

The purpose of this letter is to outline some of the factors which should be considered if you are using or planning to use alternative fuels. The enclosure summarizes some of these safety issues. This is not a comprehensive listing of all of the safety issues related to alternative fuel usage, and should not be considered comprehensive guidance in assessing the safety of an alternative fuel program. It is, however, an important beginning.

The FTA will distribute guideline documents for facility design, construction, and operation of alternative fueled buses to all FTA bus grant recipients as soon as they are complete. Until then, I urge you to make a careful safety review (hazard analysis) of your procedures for handling alternative fuels at your facilities, taking into consideration the issues raised in the enclosure.

Sincerely,

Gordon J. Linton

Enclosure

FEDERAL TRANSIT ADMINISTRATION DISCUSSION OF SAFETY ISSUES RELATED TO ALTERNATIVE FUELS USAGE

Background:

Compressed natural gas (CNG) is currently the most widely used alternative fuel in transit buses. The primary hazards associated with its use are related to its flammability and high storage pressure. CNG is lighter than air and will rise if released. Thus, measures should be taken to prevent accumulation of vapors near the ceiling of indoor spaces. The fuel is stored on board the vehicle at pressures of 3000-3600 psi. The gas is odorized so that personnel can generally smell leaks. Research has shown, however, that personnel frequently exposed to the odor of CNG lose some ability to detect it.

Liquefied natural gas (LNG) is natural gas which has been cooled to below its boiling point (-260 degrees Fahrenheit) so that it becomes a liquid. The fuel is stored on the vehicle in cryogenic liquid form in vacuum-bottle type containers. The fuel is vaporized and provided to the engine in gaseous form. Unlike CNG, LNG has absolutely no odor, and thus cannot be detected by smell. The extremely low temperature of the fuel requires special handling procedures. 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.

Alcohol fuels, methanol and ethanol, are colorless liquids. Both are more easily ignited than diesel fuel, and their vapors, which are heavier than air, can accumulate near the floor and in maintenance pits. Skin exposure to liquid methanol should be avoided due to its toxicity. Ethanol, though less toxic, still can present similar hazards to personnel.

Liquefied petroleum gas (LPG), commonly known as propane, is a heavier than air gas which is stored in liquid form at moderate pressures (25-200 psi). Leaking LPG can accumulate near the floor and in pits, and is easily ignited.

FTA on-site surveys have been conducted at facilities using CNG, LNG and methanol.

Site Safety Survey Findings:

To assure a level of safety in the use of alternative fuels equivalent to that of diesel fuel, operational and facility changes are necessary to accommodate the specific characteristics of the fuel being used. Experience to date has shown that these changes are best broken down into five areas:

Management:
Appropriate management attention to the need for the safe handling of alternative fuels is essential. A hazard analysis should be performed and used to develop specifications for system modifications and appropriate written safety procedures. Specific management actions which contribute to a safe alternative fuel operation should be included in these written procedures, such as: definition and delegation of safety program responsibility, an emergency response plan in cooperation with local public safety officials, and an annual safety audit of the alternative fuel operation.

Facilities:
Survey experiences to date have uncovered some concerns associated with maintenance, fueling, and storage facility design and operation. Since natural gas is lighter than air, ignition sources such as open flame heaters and electric motors at or near the ceiling of facilities used for storage and maintenance of vehicles should be avoided. Existing ignition sources such as sparks or open flames should be removed from these areas. Ventilation rates in storage facilities should be adequate to prevent unhealthy air quality levels from occurring during pull-out and to assure that should a major fuel leak occur from a bus fuel system, any resulting flammable plume would be quickly dissipated. Gas detection equipment should be provided in any facility using natural gas fuels; this is especially of concern with LNG, since LNG vapors cannot be detected by smell.

Appropriate industry guidelines such as those provided by the National Institute for Occupational Safety and Health (NIOSH), National Fire Protection Association (NFPA) (NFPA Standards #52 and #57), should be referred to in the design of new or modified facilities to accommodate alternative fuel vehicles. However, many National and local codes for building construction have not been updated for the current array of alternative fuels. Until controlling regulations and standards are in place for each alternative fuel, each transit agency should seek the cooperation of local public safety officials and the services of experienced architects and engineers to assure appropriate levels of workplace safety.

Operations:
For the most part, alternative fueled vehicles are operated in the same way as their diesel powered counterparts. Operators and local public safety officials should be made aware of the characteristics of the alternative fueled vehicles along with the precautions and procedures which should be implemented in the event of an accident or other emergency.

Fueling operations for alternative fuel vehicles differ from that of diesel vehicles. Alcohol fuels require precautions related to their flammability and toxicity. CNG vehicles are fueled by a high pressure hose and connector. During fuel transfer and removal, grounding and bonding are necessary to prevent static discharges and the resultant sparks.
Unenclosed CNG compressors can produce noise levels which would necessitate hearing protection for employees. Fueling technology for LNG vehicles is not yet mature, but is progressing rapidly. The fueling of LNG vehicles is a complex process which requires extensive training and precautions.

Maintenance:
Maintenance on fuel systems on alternative fueled vehicles requires special precautions and should only be performed by qualified and trained personnel. Alcohol fuels require precautions to prevent skin contact and to assure that there is adequate ventilation. Proper precautions should be taken when performing any maintenance on the fuel system of an alternative fueled vehicle, such as elimination of or restrictions on the use of spark producing equipment, welding torches and similar devices near the vehicle. Appropriate precautions should be taken with regard to the handling of high-pressure CNG fueling lines and cryogenic LNG fuel system components.

Training:
Appropriate training and periodic re-training for all personnel associated with the operation and maintenance of alternative fueled vehicles is necessary to ensure adequate levels of safety. All personnel should be aware of the characteristics of and hazards associated with the particular fuel being used, as well as the appropriate procedures to minimize the risks associated with those hazards. Documents which set forth emergency procedures should be easily accessible to all personnel likely to have a need for them.

Summary:
Safe operation of alternative fueled vehicles in the transit environment requires:

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

Consideration of these issues will minimize the risks associated with operating alternative fueled vehicles in the transit environment.

APPENDIX B
TRANSIT AGENCY QUESTIONNAIRE

TRANSIT AGENCY QUESTIONNAIRE
Transit Cooperative Research Program, Topic SC-1:
"Safe Operating Procedures for Alternative Fuel Vehicles"

Transit Agency: ____________________ Contact: ____________________
Address: ____________________ Telephone: ____________________

1. Please attach your most recent annual report or other document containing general information and statistics about your transit operation.
2. Please list alternative fuels used in your fleet: ____________________
3. Please indicate which of the following alternative fuel configurations are used in your fleet:
   - Dedicated 100% alternative fuel ______
   - Pilot ignition diesel with alternative fuel (maximum energy substitution = _____%) ______
   - Flexible fuel (mixture of gasoline and alcohols (maximum alcohol content = _____% vol/vol) ______
4. For each alternative fuel chassis/engine combination in your fleet, please indicate:

Fuel			
Chassis (Mfr, Model, Year):			
Bus length:			
Number of vehicles:			
GVWR:			
Engine (Mfr, Model, Year):			
Fuel System Mfr			
Fuel System Installer:			
Total miles for type, all units:			
Annual average miles, per unit:			
Expected life of vehicle:			

5. Please describe any accidents/incidents involving alternative fuel since its introduction at your agency, and note any measures taken to minimize their recurrence.
6. Please list the applicable rules, codes and regulations for the alternative fuels that you use at your operations.
   - Vehicle: ____________________
   - Fueling: ____________________
   - Maintenance: ____________________
   - Training: ____________________
   - Other: ____________________
7. Please note any significant changes in your facilities and operations that you initiated to accommodate alternative fuels and their safety requirements.

(If you need more room to respond, please use the back of this page.)

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8. Please describe any constraints that alternative fuel use placed on your operations (e.g., safety practices, refueling, range).
9. Please indicate any activities you had to relocate for alternative fuel buses.

	Usual Location	Alternative Fuel Location
Refueling		
Maintenance		
Inspections		
Other		

10. Please describe your alternative fuel safety program for drivers, mechanics, and other personnel.
    - Formal instruction ____________________
    - Handouts/safety manuals ____________________
    - Other ____________________
11. Please describe refueling provisions for your alternative fuel vehicles:

Fuel			
Facility location			
Owner/Operator			
Nozzle type (Mfr, Model)			
Flowrate (max/min)			
Storage capacity			
Tank construction			
Tank location (e.g., underground)			
CNG cascade operating pressure			
CNG compressor capacity			
Fuel supplier			

12. Please describe any issues you have had relative to refueling, e.g., slow fill, supply interruptions, etc.
13. Please comment on the following relative to your experience in implementing alternative fuels at your agency:
    - Availability of design/construction/safety codes or guidelines ____________________
    - Applicability and clarity of codes or guidelines ____________________
    - Availability and performance of contractors ____________________

(If you need more room to respond, please use the back of this page.)

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13. (Continued)

Availability and suitability of equipment ______

Do you feel that hazards may exist which aren't addressed by existing safety codes? (If yes, please describe)

Do you feel that there are any safety requirements which are onerous and unnecessary? (If yes, please describe)

14. Please list the factors that prompted your organization to become involved with alternative fuel vehicles.

15. What was your initial reaction/opinion to using alternative fuels? ______

16. How has your opinion changed with experience? ______

17. Please note any benefits that have resulted or that you expect from use of alternative fuels by your agency, beyond enabling compliance with governmental regulations.

18. What are the disadvantages of using alternative fuels in daily operations, if any? ______

19. From your experience, what problems/difficulties do you feel should be addressed in the future with regard to alternative fuel vehicles?

20. Please provide any comments or anecdotes you would like to relate concerning alternative fuel vehicles that have not been uncovered in this questionnaire.

THANK YOU!

Please return questionnaire to:

Acurex Environmental Corporation
Attn: P. Hill
P.O. Box 7044
Mountain View, CA 94039

(If you need more room to respond, please use the back of this page.)

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APPENDIX C
TRANSIT AGENCIES SURVEYED

Transit Agency	Location	Alternative Fuels Used (Buses)	Total Buses
Arizona (2)			
City of Tuscon Mass Transit System	Tucson	Natural gas (3)[a], natural gas/diesel (3)	180
City of Phoenix Transit System	Phoenix	Diesel[b](3), methanol (2)	338
California (4)			
Alameda-Contra Costa Transit District	Oakland	None	872
Los Angeles County Metropolitan Transportation Authority	Los Angeles	Diesel[b](22), methanol (42), natural gas (11)	2,469
Orange County Transportation Authority	Garden Grove	Methanol (2), natural gas (2), propane (163)	755
Santa Barbara Metropolitan Transit District	Santa Barbara	Battery/electric (6)	75
Colorado (2)			
Regional Transportation District	Denver	Battery/electric (6), methanol (5)	766
Transfort	Fort Collins	Propane (3)	n/a
Connecticut (2)			
Greater Bridgeport Transit District	Bridgeport	Kerosene (53)	57
Norwalk Transit District	Norwalk	Diesel[b] (19)	25
Florida (1)			
Pinellas Suncoast Transit Authority	Clearwater	Diesel [b] (10)	172
Illinois (1)			
Decatur Public Transit System	Decatur	Diesel/ethanol (5)	26
Michigan (1)			
Manistee County Transportation	Manistee	Propane (19)	24
Missouri (1)			
Bi-State Development Agency	St. Louis	Diesel[b] (2), natural gas (2)	700
Montana (1)			
Transit Management of Great Falls, Inc.	Great Falls	Diesel[b] (14)[a]	15
New Jersey (1)			
New Jersey Transit Corporation	Newark	Natural gas (5)	2,624
New York (2)			
New York City Department of Transportation	New York	Methanol (6), natural gas (2)	na
New York City Transit Authority	Brooklyn	Diesel[b] (400)	3,964

North Carolina (2)			
AppalCART	Boone	Propane (6)	16
Chapel Hill Transit	Chapel Hill	Kerosene (54)	56
Ohio (1)			
Greater Cleveland Regional Transit Authority	Cleveland	Natural gas (15)	769
Oklahoma (1)			
Central Oklahoma Transportation and Parking Authority	Oklahoma City	Natural gas/gasoline (9)	100
Oregon (1)			
Tri-County Metropolitan Transportation District of Oregon	Portland	Propane (32)	569
Pennsylvania (1)			
Lehigh & Northhampton Transportation Authority	Allentown	Battery/electric (1)	90
Texas (2)			
Capital Metropolitan Transportation Authority	Austin	Gasoline/natural gas (27), propane (2)	265
Metropolitan Transit Authority of Harris County	Houston	Natural gas (11)	1,020
Washington (1)			
Pierce County Public Transportation Benefit Area Authority Corp.	Takoma	Natural gas (34)	172

[a] The number in parentheses after each of the fuels denotes the number of fleet vehicles using that fuel.
[b] Diesel with particulate trap.

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