DOT-FTA-MA-90-7007-95-3
DOT-VNTSC-FTA-95-10

U.S. Department
of Transportation
**Federal Transit
Administration**

Clean Air Program

Liquefied Natural Gas Safety in Transit Operations

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

March 1996
Final Report

OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION

REPORT DOCUMENTATION PAGE

PB96178447

2. REPORT DATE
March 1996

3. REPORT TYPE AND DATES COVERED
Final Report - September 1994

4. TITLE AND SUBTITLE
Liquefied Natural Gas Safety in Transit Operations

5. FUNDING NUMBERS
U5022/TT422

6. AUTHOR(S)
David M. Friedman*; Norman D. Malcosky**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**Battelle
505 King Ave.
Columbus, OH 43201

*Science Applications International Corp. (SAIC)
1710 Goodridge Dr.
McLean, VA 22102

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FTA-95-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Transit Administration
Office of Research, Demonstration and Innovation
400 7th Street, SW
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT-FTA-MA-90-7007-95-3

11. SUPPLEMENTARY NOTES
This work performed under contract to:
U.S. Department of Transportation
Volpe National Transportation Systems Center
Cambridge, MA 02142

Subcontractors to Battelle
Gannett Fleming, Inc., Harrisburg, PA
Technology & Management Systems, Inc., Burlington, MA

Subcontractors to SAIC
PAI, Inc., Falls Church, VA
STAR Environmental, Torrance, CA

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report examines the safety issues relating to the use of Liquefied Natural Gas (LNG) in transit service. The safety issues were determined by on-site surveys performed by Battelle of Columbus, Ohio, and Science Applications International Corp. (SAIC) of McLean, Virginia of four transit agencies using LNG. The surveys consisted of: 1) extensive interviews; 2) review of records, procedures, and plans relating to safety; 3) examination of facilities and equipment; 4) observations of operations including fueling, maintenance, morning start-up, and revenue service; 5) measurement of methane concentrations in the air where the buses are being fueled or stored. Interviews included all job categories associated with management, operations, safety, maintenance, acquisition, and support. In general operations at the sites observed are safe. Some safety deficiencies were noted and are given. The surveys also included an examination of the occupational hygiene aspects of LNG use. Survey results showed that differences exist between transit agencies in their mitigation of LNG hazards.

14. SUBJECT TERMS
Alternative fuels, transit buses, liquefied natural gas, safety, fueling, facilities, emergency planning, training, fire codes

15. NUMBER OF PAGES
132

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)]°F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5)(y + 32)]°C = x°F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0		1			2			3		4			5
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

Updated 9/29/95

PREFACE

In November 1992, the Volpe National Transportation Systems Center in its support for the Federal Transit Administration's (FTA) Clean Air Program, initiated an industry survey of safety in transit agencies using Liquefied Natural Gas (LNG) as an alternative fuel in bus operations. The results of that survey, presented in this report, examine the safety issues as determined from a survey of four transit agencies using LNG. The on-site examinations were performed by Battelle of Columbus, Ohio and Science Applications International Corporation (SAIC) of McLean, Virginia. Each company visited two different cities.

One of the conditions of this survey was that the individual transit agencies would not be individually identified in the final report. The survey was not intended as a safety investigation, but rather as an industry practices survey and expressing findings of specific agencies was not the intent of the project. A parallel survey by the same contractors examined the use of Compressed Natural Gas (CNG) in transit activity. The results of that survey is reported in a companion report.

Each contractor submitted summary reports to the Volpe Center which are reproduced in this document. Each contractor surveyed different agencies and each presented their material somewhat differently, although many of the observations and conclusions are similar. Both reports are generally consistent in the hazards which they describe. However, readers should examine both as the two complement each other.

> **In both reports, Battelle and SAIC, along with observations and evaluations, present recommendations and conditions which they suggest should be followed to provide safe use of LNG in transit operations. They both also say that local fire and other code officials have final approval authority. <u>The Federal Transit Administration has no facility regulatory authority.</u>**

Appreciation is given to the transit agencies which permitted their activities to be reviewed and to their personnel for the time and effort given in cooperating with the survey teams. In conducting the site visits, Battelle was assisted by Gannett Fleming of Harrisburg, PA, and Technology & Management Systems, Inc., of Burlington, MA. SAIC was assisted by STAR Environmental of Torrance, CA and PAI, Inc., of Falls Church, VA. Providing program guidance were Vincent DeMarco and Steven Sill of the Federal Transit Administration. William Hathaway of the Volpe National Transportation Systems Center provided technical safety direction. Overall review of the project and preparation of this report was provided by David Knapton of the Volpe Center.

SECTION I
TABLE OF CONTENTS

SECTION I
TABLE OF CONTENTS
(Continued)

SECTION I
LIST OF FIGURES

Figure | Page

SECTION I
LIST OF TABLES

Table | Page

SECTION II
TABLE OF CONTENTS

SECTION II
TABLE OF CONTENTS
(Continued)

SECTION II
TABLE OF CONTENTS
(Continued)

SECTION II
LIST OF FIGURES

SECTION II
LIST OF TABLES

EXECUTIVE SUMMARY

The Clean Air Program was established by the Federal Transit Administration (FTA) to support the national goals of reducing both vehicle emissions and petroleum imports. In its dual role of promoting transit and of encouraging safe operations, the FTA established an alternative fuel bus demonstration program and an industry survey of safety practices in transit agencies using alternative fuels. An earlier survey conducted in cooperation with the National Institute for Occupational Safety addressed the occupational health and safety of fueling, maintenance, and operation of methanol-powered transit buses.* The study reviewed in this report examines the safety issues of Liquefied Natural Gas (LNG) buses as determined from a survey of four transit agencies using LNG in revenue operations. The review was performed by Battelle of Columbus, Ohio and Science Applications International Corporation of McLean, Virginia. One of the conditions of this survey was that the individual transit agencies would not be individually referenced in the final report. The survey was not intended as a safety investigation, but rather as an industry practices survey and expressing specific findings was not the intent of the project. A parallel survey by the same contractors examined the use of Compressed Natural Gas (CNG) in transit activity. The results of that survey are reported in a companion report.

The individual surveys consisted first of an agreement with each agency to allow the FTA and its contractor to perform the survey. A survey plan was then designed and submitted to each agency. The site visit began with a briefing of objectives and discussion between the team and the transit agency. This allowed the scope of the survey to be understood by both parties and for establishing a schedule of specific interviews and for determining the components of the system to be examined. The survey team consisted of one or two FTA personnel, the contractor with three investigators, and several subcontractor and consultant specialists selected by each contractor. Each on-site survey took three or four days, and at the completion of each survey the contractor reported their observations to the transit agency. The survey itself consisted of: 1) extensive interviews; 2) review of records, procedures, and plans relating to safety; 3) examination of facilities and equipment; 4) observation of operations including fueling, maintenance, morning start-up, and revenue service; and 5) measurement of methane concentrations in the air where the buses are being fueled or stored. Interviews included all job categories associated with management, operations, safety, maintenance, acquisition, and support. The observations were submitted to each agency in the form of trip reports and which allowed

* For example, "Industrial Hygiene Survey Report of Seattle Metro, Ryerson Base," Greg Piacitelli, National Institute for Occupational Safety and Health, Report Number 163.2.01, August, 1990.

the agency to correct any factual errors and to suggest any differences in interpretations of safety practices.

LNG is a condensed (liquified) form of natural gas which is produced by cooling. It is stored at cryogenic temperatures (minus 260 degrees fahrenheit, or less and pressure up to 150 psi) in large (10,000-30,000 gallon) dual-walled, insulated, pressure vessels designed to withstand the low temperatures and elevated pressures. It is dispensed to the fuel tanks on the bus by a cryogenic pump or a pressure transfer technique. LNG is composed primarily of methane and has similar properties to methane.

LNG is not inherently more dangerous than conventional fuels. However, it is different and the differences can create hazards for personnel unfamiliar with its properties. Methane, the principle constituent of natural gas, is lighter than air, hence it tends to rise when close to the temperature of the surrounding air. LNG leaks, however, will be very cold and will sink to the lowest available surface and may disperse close to the ground for a significant distance. Hazards relating to LNG are fire, cryogenic burns when coming into contact with flesh, changes in properties of materials, and asphyxiation by displacing oxygen from victims. Ignition can come from contact with hot surfaces, open flames, and sparks, including static electricity.

Comparing the operational features of LNG to the more commonly used CNG in transit reveals some of the important issues pertaining to LNG. A transit agency does not have to be connected to the gas distribution network to use LNG. LNG is brought to the agencies by truck and thus the transit agency can be remotely located. LNG has an advantage over CNG in that it is a liquid and stored at a low pressure, compared to CNG. A bus having an LNG fuel system weighs approximately 1000 pounds less than one with a CNG fuel system. Pressure in CNG tanks can be up to 3500-4000 psi, while LNG pressures are up to 150 psi. LNG systems, therefore, are not exposed to the high pressure hazards of CNG systems. One characteristic of LNG which differs from CNG is that because of LNG's low temperature, odorants can not be added, resulting in an increased hazard in the event of a leak as workers cannot detect an odor.

Safety of the LNG activity at the sites surveyed was judged by a combination of criteria, such as national codes and their interpretation, practices and lessons learned by the survey team from observations at other sites, and the combined experience of the investigation team in transit and industrial safety and occupational health. In general, operations at the sites observed are safe. Some safety deficiencies were noted and are detailed below. Transit authorities have made significant strides to build an infrastructure for safe operations with LNG. Workers involved with LNG operations generally appeared highly motivated and interested in safety, but the agencies varied widely in terms of the type of training given, the amount of LNG safety information available on the shop floor, and the amount of objective information obtained. One of the most important resources in safe operations is a clear understanding by employees of LNG hazards, knowing and following safe practices, and understanding and remembering the proper emergency response procedures. More and better training is almost a universal need. There is an ever present possibility of rules being overlooked and unsafe conditions being created. The surveys also included an examination of the occupational hygiene aspects of LNG use. With few exceptions, such as cryogenic fuel leakage from fueling nozzles (vapor venting during fueling) and the need for more careful considerations of asphyxiation hazards, the work environment at the facilities was good. There is nothing inherently noisy about refueling, operating, or maintaining LNG vehicles.

No one site was found to be best in all safety aspects of LNG operations. In general, a problem for the transit industry in converting to LNG operations is a lack of technical and procedural guidance. Each transit agency has had to learn from start and to profit from its own experience. Differences exist from transit agency to transit agency on hazard and consequence mitigation measures such as: 1) methane monitoring in the facilities including procedures and action upon the detection of methane; 2) control of strong ignition sources including maintenance and storage facility installation of explosionproof electrical systems; 3) number of air exchanges per hour for facilities which store and/or maintain buses; 4) fueling/defueling practices; and 5) emergency preparedness both for incidents within facilities and for buses in services.

While the technology for cryogenic fuels has been highly developed for other uses, the transfer of LNG from the bulk transporter arriving at the transit agencies' fueling facilities and the fueling of the buses showed leaking and fuel loss in both cases. The fuel transfer technology is the least developed in LNG bus operations.

A hazard encountered in the site reviews was the use of open flame gas space heaters installed near the ceiling of buildings where buses are garaged and serviced for maintenance. In the case of an accidental release of LNG within a structure having open flame heaters, there will be a chance of a fire. Other strong ignition sources were observed including such equipment as fan drives and door opening devices.

Unresolved issues that were identified during the survey that transit agencies should consider are: 1) code coverage and interpretation and building and equipment standards; 2) gas detection including the location of detectors, reliability and calibration requirements, and response of remedial action; 3) the path, concentration, and duration of escaped gas; 4) the hazard of interior facility formaldehyde buildup with larger fleets as formaldehyde was detected during the survey; and 5) actual risks associated with the hazards to more clearly identify the safety and costs associated with the options the industry faces.

SECTION I

STATUS OF LNG SAFETY IN TRANSIT APPLICATIONS

Science Applications International Corporation
McLean, VA

Gary M. DeMoss
David M. Friedman

P.A.I.
Falls Church, VA

George J. Pastor

STAR Environmental
Torrance, CA

Jeffrey Harrison

1. INTRODUCTION

The FTA has been sponsoring a national demonstration program titled the Alternative Fuels Initiative (AFI) since 1988. Under this program, various alternative-fueled transit vehicles (primarily transit buses) are introduced into regular transit service. While not charged with any major regulatory responsibility over public transit, the FTA does have limited safety oversight and reporting responsibility. Consistent with this authority, the FTA, through the Volpe National Transportation Systems Center (Volpe Center), engaged Science Applications International Corporation (SAIC) and its subcontractors to conduct a safety assessment based on surveying a sample of transit bus operations using Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG). The results and experiences gained from these surveys form the basis of this report on LNG and its companion report on CNG.

1.1 OBJECTIVE

The objective of this report is to provide a safety assessment of selected transit agencies using LNG buses. A companion report provides a similar assessment of transit agencies using CNG buses. Taken together, the specific objectives are to:

- Provide an assessment of the safety and operational characteristics of CNG- and LNG-fueled transit buses and their attendant fueling and other support systems, based on a limited survey of actual, introductory operations of these vehicles.

- Establish an initial safety information database for the use and benefit of the FTA and the transit community, to assist them in their future decisions with respect to the selection of alternative-fueled buses and, in general, to learn from the initial experiences of their peers.

1.2 BACKGROUND

Federal actions such as the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, and Executive Order 12759 mandating the acquisition of Alternative-Fueled Vehicles (AFVs) by Federal fleets, established an ambitious schedule for introducing AFVs, including buses. In addition, several states have introduced their own fleet and fuel requirements.

Fuel supply distribution and infrastructure requirements make large fleets of centrally-fueled vehicles ideal candidates for AFV use. Transit buses, which number more than 50,000 nationally, are among the vehicles whose operational and fueling characteristics make them relatively well-suited for AFV use, including CNG and LNG use.

Many of the transit agencies who participated in the early introduction of one or more types of AFV buses were essentially writing the rules as they went. The absence of formal or central rules or regulations on CNG or LNG bus use creates a need to capture the lessons learned thus far and pass them along to others. This requirement holds for performance at all levels, training, maintenance, operations, acquisition, and so forth. One of the greatest needs, given the importance of transit, is for information on safety.

Wide differences exist from transit agency to transit agency on hazard and consequence mitigation measures, such as methane monitoring, maintenance facility air exchanges, fueling/defueling practices, and emergency preparedness. Similarly, wide differences in bus design, particularly tank placement and venting arrangements, are common. There are no standards for emergency response, passenger evacuation, system shutdown, staff training, and other safety factors.

Transit agencies may view their ATF programs as experimental, fully commercial, or something in between. This perspective explains certain decisions over capital investments and training programs. It does not, however, ensure safe operations. To address this situation, the FTA is attempting to develop usable information and guidance on safety issues. As an assistance-oriented agency, FTA's role is to provide such information to the transit agencies, bus suppliers, user organizations, localities, and others.

The material in the present report is a safety assessment. A safety assessment identifies hazards and hazardous activities, practices, and designs, among other issues. In the case of LNG buses (or, more generally, LNG systems), these hazards are cryogenic (cold), fire, and asphyxiation. Hazardous activities include indoor maintenance on buses with LNG in the fuel tanks and the use of open flame heaters in maintenance facilities. Non-LNG hazards from buses are not discussed.

A safety assessment does not quantify risks or consequences or recommend modifications to practices, equipment, or structures. Thus, there is no discussion of the likelihood or the consequences of a fire initiated by an open flame heater in an indoor maintenance facility. There is only the recognition of the hazard. The FTA may wish to consider additional research in these areas to evaluate risks and consequences.

1.3 APPROACH

The approach to the present task included in-depth on-site interviews and investigations at two transit agencies using LNG buses, reviews of bus and LNG/CNG safety literature, and comparison of LNG safety findings with similar findings from the investigations at three agencies using CNG buses. The Gas Research Institute report, *Introduction to LNG Vehicle Safety*, was particularly important in developing the present report. Excerpts from this report were used liberally to help explain certain fuel- and safety-related issues.

The safety assessments included vehicle safety, maintenance facilities and techniques, operations, fueling equipment and operations, storage (parking) facilities and practices, program safety effectiveness, and emergency preparedness.

Actual site visits began with a briefing of objectives and a discussion of the proposed methods. The role of the survey team and the meaning of a safety assessment were discussed. This was followed by a site walk-through and records review. The majority of site activities included extensive interviews in all job categories associated with bus operations, safety, management, maintenance, acquisition, support, etc. Safety and operating procedures and policy changes were of particular interest. Each site visit concluded with a debriefing to management. Detailed site reports were prepared for FTA and informally shared with agency management.

1.4 CAVEATS

In reviewing this report, please note the following:

- In both the LNG and CNG reports, the safety issues are not identified with particular facilities. The objective of this report is to summarize safety at the industry level, not to report on issues by site. Separate site-specific summaries were provided to FTA and informally shared with the agencies.

- The site investigations took place in early to late 1993. Practices and facilities may have changed since that time.

- An unrelated contractor team (led by Battelle) conducted similar assessments to the ones described by the SAIC team. These assessments are reported in the second part of this document.

2. GENERAL DESCRIPTION OF LNG USE IN TRANSIT

2.1 LIQUEFIED NATURAL GAS (LNG)

LNG is a condensed (liquefied) form of natural gas. It is composed primarily of methane (CH_4) and has similar physical-chemical properties to methane. It is stored in dual-walled, insulated, pressure vessels designed to withstand cryogenic temperatures (approximately -260°F) and elevated pressure. One volume of LNG equals approximately 600 volumes of natural gas at standard temperature and pressure. When LNG is derived from pure methane, or when liquefaction includes the removal of all impurities from the natural gas, the liquid is referred to as Liquid Methane (LM). Generally, the higher the methane content of the LNG the more desirable it is for vehicle use.

2.2 LNG BUS OPERATIONS

Experience with LNG transit bus operations is very limited. The first commercial use of LNG buses began in the early 1990s. This technology is still considered to be in the developmental phase, thus, LNG bus performance relative to diesel bus performance is likely to undergo changes in the near-term. Operationally, the LNG bus technology employed at the sites visited gave the buses less range, relatively poorer performance, lower reliability, and, depending upon the technology, slower acceleration than their diesel counterparts. Over the long-term, operational differences may also arise from differences in life expectancy, life cycle maintenance and operating costs, system durability, and safety. While in revenue service, an LNG bus can be distinguished from a diesel bus by a small DOT-required placard labeled "LNG," and the absence of the visible smoke and smell associated with the exhaust of a diesel engine.

2.3 LNG BUS CHARACTERISTICS

There are significant differences between diesel and LNG buses in the fuel system, operations, fueling, maintenance, and storage. These differences affect the vehicle performance, emissions, weight, cost, maintenance and storage procedures, and safety. Two types of LNG buses were observed during this project: dedicated LNG buses with spark-ignition engines; and dual-fuel, diesel pilot-ignited engines, that used LNG only during certain portions of the duty cycle.

2.4 LNG BUS FUELING

LNG from a station storage vessel is transferred to buses via a dispenser similar in appearance to gasoline dispensers. Fuel transfer typically includes transfer hose cool-down, liquid transfer to the vehicle, and a separate line for vapor return from the vehicle to the storage vessel.

2.5 LNG BUS MAINTENANCE

Maintenance activities were performed in the general maintenance facility of the two sites visited. These maintenance areas were not designed to meet recommended guidelines (NFPA 52 and draft NFPA 57) and contained ignition sources. Each facility employed some risk-reduction strategies. Each guarded against bringing buses with LNG leaks indoors and, while indoors, periodically monitored the LNG pressure gauges on the bus. Each facility relied on the on-board gas detectors for gas leak warnings. At the time of the visits, there were no gas detectors in the maintenance facilities, although both agencies had plans to install gas detectors.

2.6 LNG BUS STORAGE AND START-UP

At the two agency sites visited the LNG vehicles were parked outdoors. One agency parked its buses under a canopy, the other in an uncovered yard. All agencies tried to avoid leaving LNG vehicles in the maintenance building overnight.

3. THE FUEL -- LIQUEFIED NATURAL GAS

At atmospheric pressure, natural gas condenses to a liquid (LNG) at approximately −260°F (−162°C). A combination of pressure and low temperature is used to maintain LNG as a liquid. The liquid is clear, weighs about half as much as the same volume of water, and is odorless, unless special efforts have been made to add an odorant.

3.1 LNG COMPOSITION

Pipeline-quality natural gas typically contains 85-99 percent methane (CH_4). It also contains heavier hydrocarbons, including ethane (C_2H_6), propane (C_3H_8), some butanes (C_4H_{10}), and trace amounts of five-carbon (pentane) and higher species. Nitrogen, carbon dioxide, water, and trace amounts of helium and hydrogen sulfide are also present. Before liquefaction, carbon dioxide, water, hydrogen sulfide, and other trace components that could solidify at LNG temperatures (including odorants) are removed. At least one engine manufacturer requires a minimum of 92-95 percent methane in the LNG.

3.2 LNG PROPERTIES

The properties of LNG are similar to those of pure methane. Important properties of LNG, with related safety implications, are summarized below:

- Autoignition Temperature: Autoignition temperature is the lowest temperature at which a gas will ignite after a lag time (i.e., several minutes). This temperature depends on factors such as the air-fuel mixture and pressure. The average autoignition temperature for pure (100 percent) methane at atmospheric pressure is 1202°F (650°C). As the concentration of heavier hydrocarbons in LNG is increased, the autoignition temperature is lowered.

- Ignition Energy: The minimum spark ignition energy required to ignite the most flammable mixture of methane in air is 0.29 mJ (millijoule). Practically speaking, most sparks have enough energy to ignite a flammable mixture of methane in air.

- Flammability Limits: Flammability limits express the amount of a fuel that must be present in air for the fuel to burn (assuming air contains 21 percent oxygen). The lower and upper flammability limits for methane in air are 5 percent and 15 percent by volume, respectively.

- Boiling Point: At atmospheric pressure (14.7 pounds per square inch), methane boils at −259°F (−162°C). An increase in storage pressure raises the boiling point. In pressurized LNG storage vessels (at approximately 35 psi), methane boils at about −237°F (−149°C). Figure 1-1 shows the effect of pressure on the boiling point of methane.

- Heat of Vaporization: Latent heat of vaporization is the heat required by a substance when changing from a liquid to a gas (220 Btu/lb (511 kJ/kg) for methane). The heat of vaporization contributes to cold burns because, in addition to the initial low temperature of the liquid, the vaporizing LNG absorbs heat from its surroundings. Thus, the potential for burns is greater for a cryogenic liquid than for an equivalent temperature gas.

- Density and Specific Gravity at Standard Temperature (60°F): Density is the mass of a substance per unit-volume. Specific gravity is the density of a substance compared to the density of a standard substance, usually water or air, depending on whether the comparison is with a liquid or a gas. The density of methane at atmospheric pressure and standard temperature (60°F or 16°C) is 0.0424 lb/ft^3. The specific gravity of methane under the same conditions is approximately 0.55.* At standard temperature, methane rises in air.

- Density and Specific Gravity at Low Temperatures: The density of methane increases as temperatures decrease. This behavior affects the dispersion of a cold vapor cloud. At temperatures below −160°F (−107°C) the density of methane is greater than that of air at 60°F. Cold LNG vapor accumulates in low areas until it warms.

---

* A gas with a specific gravity greater than 1.00 is heavier than air (i.e., it will tend to stay near the ground and will not easily disperse into the air). Conversely, a gas with a specific gravity less than 1.00 is lighter than air and will easily disperse in well-vented areas.

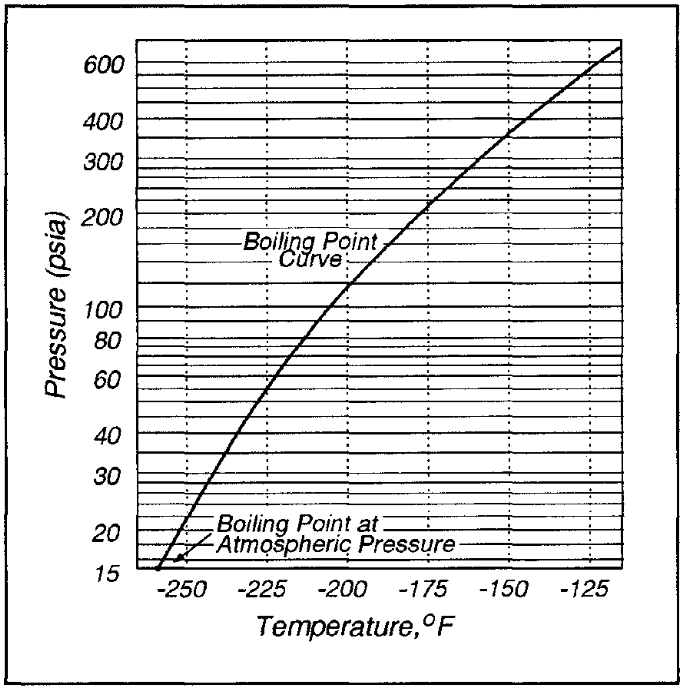

Figure 1-1. The Effect of Pressure on the Boiling Point of Methane

3.3 LNG HAZARDS

The use of LNG presents hazards in three areas: cryogenics, fire, and asphyxiation.

- Cryogenic Hazards -- Exposure to low temperatures may cause cryogenic burns. As with heat burns, cryogenic burns may permanently damage tissue. Materials that are not designed for cryogenic applications often lose ductility, tensile strength, or impact resistance at low temperatures, which may make them unsuitable for their intended applications until they are returned to normal temperatures. Materials for cryogenic applications may not cool evenly, causing uneven shrinking and consequential loss of seals, and LNG leaks during cool-down.

- Fire Hazards -- LNG vapors that form above a pool of unconfined LNG can burn. LNG vapor cloud explosions* may occur in confined areas. Fire and explosion hazards faced by personnel include thermal radiation (heat) burns from fire and contact with hot surfaces, inhalation of combustion products, and physiological effects of a pressure wave from an explosion or associated fragments and projectiles. In an LNG fire, materials such as wood, rubber, most plastics, and fabric will ignite, and metals will soften and may melt. LNG fire and explosion conditions are summarized below.

  Natural Gas (i.e., LNG vapor) is flammable in air (which contains 21 percent oxygen) at concentrations of 5 percent to 15 percent. In well-ventilated areas, this concentration range may be reached in a small region near the leak source. In enclosed areas, flammable concentrations are more easily reached over a large area. Ignition of a flammable cloud (all of which may *not* be visible) results in flame propagation from the ignition source to the source of the gas. When an LNG vapor cloud above a spill is ignited, the burning vapor prevents further vapor cloud formation (i.e., the vapor is burned before another cloud can form). Flame size over a burning LNG pool is usually largest when the accumulated vapor cloud is first ignited. After the accumulated vapor has burned, a smaller, stable fire burns vapor as it forms. Because a pool fire lasts longer than a vapor cloud fire, areas adjacent to the fire may receive a significant amount of heat. As a result, hazardous areas associated with pool fires may extend beyond the fire itself.

  For methane to explode, it must be confined (as in a closed room or a very dense field of obstructions).** Flame speeds are too slow to produce the pressure front needed for an explosion in unconfined areas. However, in partial confinement a flame front can accelerate, generating turbulence and, ultimately, a dangerous pressure front. The density and extent of obstructions, therefore, can directly affect the severity of an explosion. Furthermore, cold, heavier-than-air LNG vapor can flow into confined spaces and may explode if ignited.

* An explosion is defined as the sudden release of pressure and generation of high temperature as a result of a rapid change in chemical state.

**"Explosion" refers to the formal term "deflagration," not "detonation."

- Lung Damage and Asphyxia -- LNG vapor is not toxic but lung damage may occur from prolonged exposure to cold vapor. Cold vapors cause breathing discomfort, which usually gives personnel sufficient warning to leave cold areas before permanent lung damage occurs.

  In a large LNG release, LNG vapor can displace sufficient oxygen from the air to cause asphyxia. When 25 percent of the air is displaced by LNG vapors, oxygen concentrations are reduced from 21 percent to 16 percent. At these levels, moderate symptoms of asphyxia may occur, including reduced judgement and increased frequency of errors in tasks. Greater air displacement may result in dizziness and, ultimately, unconsciousness. Under most LNG leak scenarios, asphyxia is not likely.

4. LNG SOURCES AND STORAGE

4.1 LNG SOURCES

LNG is liquefied from natural gas or pure methane. The primary sources of LNG are listed below:

- Commercial Gas Processing Facilities -- LNG is a by-product of some gas processing operations, such as in de-nitrogenation of gas and ethane recovery. The operators of these facilities sell by-product LNG to vehicle operators. LNG transport to customers is usually via truck.

- Utility Peak-Shaving Facilities -- Some gas utilities liquefy natural gas to store for peak periods. The LNG is stored in vessels containing as much as 200,000 gallons of LNG. Utilities may use truck or rail to ship the LNG to smaller, regional storage sites, and may sell LNG to vehicle operators.

- Import Terminals -- The U.S. has two operating LNG import terminals and others on standby. LNG is stored at the import terminals and transported by truck or rail.

- On-Site, Small-Scale Liquefaction -- Liquefaction units can be built at or near agencies with access to natural gas pipelines. However, small-scale liquefaction plants are not efficient or economical compared with bulk liquefaction and transport.

4.2 LNG STORAGE

LNG is stored in dual-walled, insulated, pressure vessels designed to withstand cryogenic temperatures and elevated pressure. One volume of LNG equals approximately 600 volumes of natural gas at standard temperature and pressure. To hold the maximum fuel volume with minimum heat transfer, the diameter to length ratio of vessels should be as large as possible (i.e., the surface area to volume ratio should be as small as possible). Vehicle tank dimensions are limited by the chassis. Figure 1-2 shows the general design of an LNG storage vessel. Baffles inside vehicle fuel tank reduce sloshing during vehicle operation. All LNG storage vessels have the following basic components:

- Inner Pressure Vessel -- commonly made of stainless steel, aluminum alloy, or other materials with favorable strength characteristics under cryogenic temperatures.

- Insulation -- usually one or more inches of insulation between the jacket (outer vessel wall) and the pressure vessel (inner vessel wall). The insulation is in a vacuum to reduce convective heat transfer. A common type of insulation for large storage tanks and truck trailers is finely ground perlite powder.* Vehicle fuel tanks typically have a thinner insulation space and use multi-layered, wrapped insulation materials.

- Outer Vessel -- generally made of carbon steel or stainless steel. Under normal operation, the outer vessel should feel the same temperature as other ambient metal surfaces.

- Support System -- suspends the inner tank within the outer tank.

- Control Equipment -- includes loading and unloading components (piping, valves, gauges, pump, etc.) and safety-related components associated with the vessel (i.e., pressure relief valve[s], burst disc, safety shutoff valves, etc.).

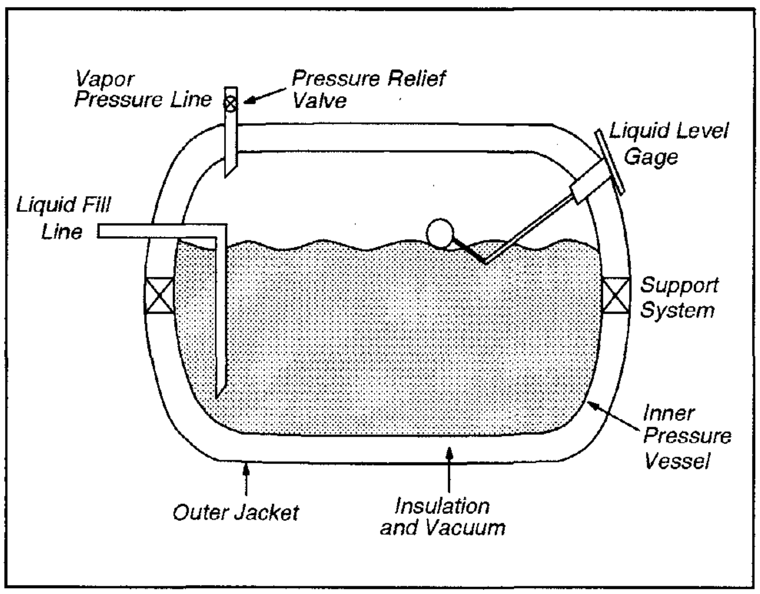

Figure 1-2. Generalized LNG Vessel

* Perlite is a light, inorganic substance that is also commonly used in gardening.

Codes and regulations that govern the structure of LNG storage vessels and fuel tanks include: the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section VII, Division 1 (design, fabrication, inspection, testing, and certification of the pressure vessel); the Code of Federal Regulations (CFR), Title 49, Part 178 (also referred to as "DOT 4L") (materials, design, fabrication, testing, inspection, and markings for containers used to transport hazardous material); and the California Code of Regulations (CCR), which specifies LNG vehicle fuel systems, references DOT 4L, and adds pressure and crash testing requirements.

5. LNG BUS OPERATIONS

5.1 OPERATIONAL EXPERIENCE

LNG bus operations are designed to be similar to those of diesel buses. Because LNG buses have been in operation for only a few years, reliability and performance histories are short and inconclusive. Because this technology is rapidly evolving, this report offers only a "snapshot" indicator of LNG bus operations in 1993. Furthermore, while there are significant differences in the technology for dedicated LNG buses and dual-fuel diesel-pilot ignited buses, no firm comparisons of these technologies can be made based on these observations at only one site with each technology. Operations at each of these sites were very different, regardless of technology.

The site with two dedicated LNG, Gillig buses reported considerable shake-down problems including fuel leaks throughout the system, insufficient fuel methane content for smooth engine performance, and supplier support issues. Acceleration was less than diesel bus acceleration. Range and availability were each 30-40 percent less than that of similar diesel buses. The reliability and performance for eight dedicated LNG, Flxible 40-foot buses with extra fuel capacity could not be evaluated because these buses had only recently arrived on-site.

The second site had a more comprehensive LNG program, and operated diesel pilot-ignited LNG buses from several bus manufacturers. Reliability, availability, and performance of these LNG buses were better than at the other agency, but not as good as their diesel counterparts. The dual-fueled buses were designed to improve performance in the lower end of the duty-cycle by operating primarily in diesel. The acceleration of these buses was similar to that of diesel buses. The combination of diesel tanks (approximately 60 gallons) and LNG tanks (approximately 120 gallons) gave these buses a greater range than dedicated LNG buses, although the range was still shorter than that of diesel buses. LNG-related problems at this site included fuel pump operation, quality control in the fabrication of LNG storage vessels and fuel tanks (e.g., loss of vacuum and insulation and the presence of metal shavings inside fuel tanks), and other less significant cryogenic system failures.

Neither agency visited for this study experienced serious driver acceptance problems. Early driver resistance was overcome by focused training. There were also some rare instances of passenger complaints of gas odors on buses that had no odorant in the LNG.

5.2 OPERATIONAL HAZARDS

Operational hazards are defined as hazards associated with LNG bus operation that are greater than the hazards associated with diesel bus operation. Worker occupational safety and health issues for LNG operations versus diesel operations were considered. The operational hazards associated with formaldehyde in LNG bus exhaust were roughly assessed with formaldehyde measurements taken at one of the LNG agencies visited. Measurements taken in the maintenance facility and at the refueling station at the operator's breathing elevation were well below OSHA threshold limit values for 10-hour worker exposure. (The source of the minimal formaldehyde concentrations measured was not confirmed.) There is no reason to expect noise levels at LNG bus facilities to be greater than at diesel facilities. LNG bus engines are noticeably quieter than diesel engines.

Specific operational hazards identified at the LNG facilities visited varied between the sites. The following operational hazards were noted at either one or both of the LNG sites visited.

- Fuel system failure - LNG buses had more fuel system failures than their diesel counterparts.

- False and premature alarms - LNG bus gas detectors produced false alarms that caused passenger concern and schedule disruptions.

- Slower acceleration - The acceleration of LNG buses is poorer than that of similar diesel buses.

- Longer stopping distances - Operators report that the heavier LNG buses require earlier application of brakes than similar diesel buses when approaching stops. This issue is of greatest concern for operators that drive both bus types.

- Greater bus weight - Many buses are at, or slightly over, the maximum allowable weight for a two-axle, 6-tire vehicle.

- Refueling leaks - LNG was released during refueling, and refueling nozzle disconnection was not always a dry-break.

6. LNG BUS CHARACTERISTICS

There are significant differences between diesel and LNG buses in the fuel system, operations, fueling, and maintenance and storage. These differences affect the vehicle performance, emissions, weight, cost, maintenance and storage procedures, and safety. There are no national codes or federal regulations that specifically address LNG bus fuel-system design and fuel-related features such as gas detectors. The NFPA has been developing standards to address LNG vehicles (NFPA 57). These draft standards include guidance on LNG fuel system components. However, NFPA 57 was not finalized at the time of these site visits in 1993. As addressed in Section 4.2, there is greater guidance for the design of LNG storage vessels and fuel tanks.

6.1 THE LNG BUS SYSTEM

This section describes the principal components of the LNG bus system. Figure 1-3 shows an LNG bus. The LNG vehicle fuel system is comprised of two types of components: those that operate at cryogenic temperatures (i.e., contain LNG or cold LNG vapors) and those that contain warmed LNG vapors (i.e., pose no cryogenic hazards).

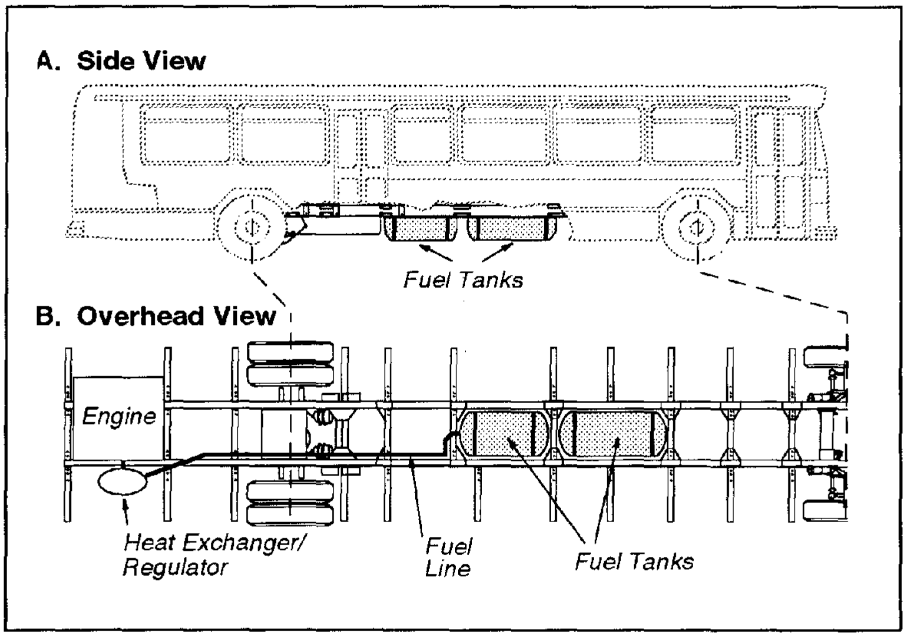

Figure 1-3. LNG-Powered Gillig Phantom Transit Bus

Figure 1-4 displays a diagram of the cryogenic components in LNG vehicles. The cryogenic components of an LNG bus run from the refueling receptacle and vent line to the vaporizer and heat exchanger. These components are briefly described below.

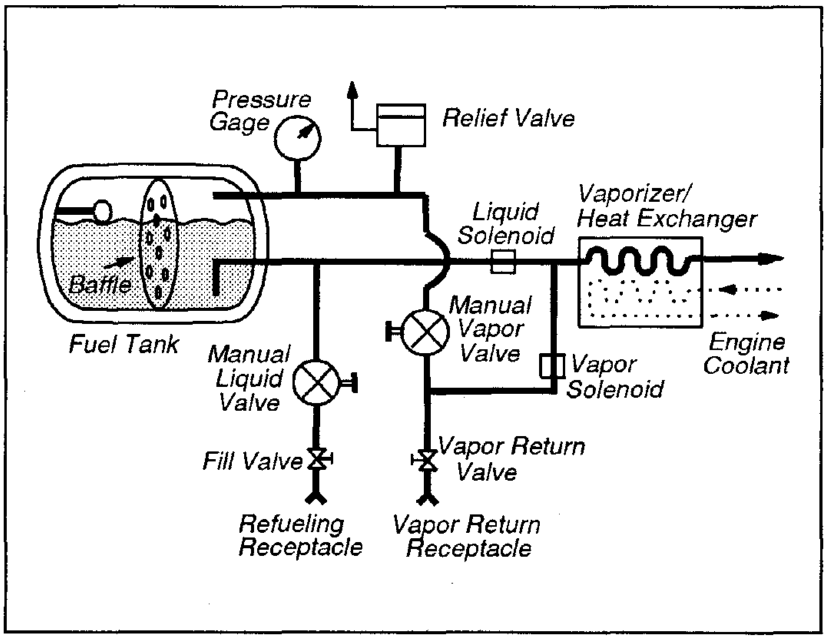

Figure 1-4. Cryogenic Components in LNG Vehicles

Cryogenic Liquid Components:

- Refueling Receptacle -- The refueling receptacle interfaces with the refueling nozzle of the LNG dispenser and allows LNG transfer to the fuel tank on the bus and venting of tank vapors. The buses observed had two receptacles, one for liquid and the other for vapor.

- Fuel Tank -- The fuel tank is insulated for on-board storage of LNG. The number of fuel tanks on the LNG buses varied with the bus manufacturer and the vintage. The dual-fueled buses generally had one large (120+ gallon) in-line fuel tank. The dedicated buses had 2 in-line tanks on the Gillig buses and three transverse tanks on the Flxible buses.

- LNG Control Equipment -- LNG control equipment on the outside of the tank consists of gauges, valves, and switches. The control equipment is attached to the end of one of the LNG tanks. In one case the control equipment was enclosed in a steel shroud.

- Fuel Line -- The fuel line carries LNG and LNG vapor from the tank to the vaporizer and heat exchanger. LNG vaporizes as it travels through the fuel line. Fuel lines are not insulated and are typically coated with frost during operation.

- Vaporizer/Heat Exchanger -- The vaporizer gasifies LNG. After gasification, the heat exchanger raises the temperature of the cold gas. Engine coolant is used as the heat source.

The non-cryogenic, vapor-phase (i.e., gas) components of a generalized LNG bus are shown in Figure 1-5, and briefly described below.

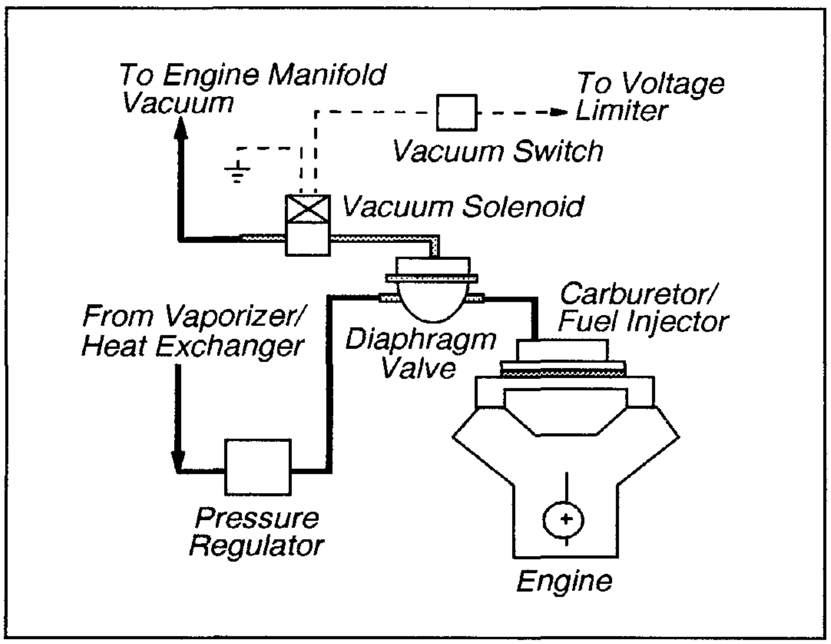

Figure 1-5. Vapor-Phase Components in LNG Vehicles

Vapor-Phase Components:

- Pressure Regulator -- The pressure regulator includes springs, a diaphragm, and a valve regulator to control gas pressure to the mixer or fuel injector.

- Fuel Injector -- For LNG buses, fuel injection is the preferred approach of delivering fuel to the engine. Fuel injection systems require a higher minimum pressure in the vapor-phase components than carburetor systems. Furthermore, because of changes in fuel density with temperature, fuel injection systems require tight control of both pressure and temperature of the injected fuel. This additional control may be achieved with additional components not listed in the described system.

- Associated Equipment -- The electrical, electronic, and structural changes to the LNG buses are minimal and do not alter the traditional look or function of the buses.

6.2 LNG BUS HAZARD DETECTION EQUIPMENT

LNG bus hazard detection equipment is designed to alert the operator to gas leaks and to mitigate engine compartment fires. The safety alert devices include gas detectors located above the fuel tank(s), along the fuel line, and in the engine compartment. Generally, the gas detectors are connected to a monitor located in the passenger compartment next to the bus operator. In the engine compartment, heat sensors are installed to detect engine compartment fires and to automatically activate a fire suppression system added to all LNG buses. At one agency, methane detectors were added inside the passenger compartment of the bus.

6.3 LNG BUS HAZARDS

This section lists aspects of LNG bus design that present hazards. The hazards listed do not necessarily apply to all of the LNG buses observed.

- Fuel system leaks and failures in on-board fuel delivery;

- LNG fuel tanks and fuel lines that extend to the bus skirt, and are protected from side-impact by only the bus skirt;

- False alarms from on-board gas detectors;

- Vehicle weight that slightly exceeds the maximum allowable weight; and

- Under-powering (poor acceleration).

From a driver perspective, these design issues result in reduced braking performance, acceleration, unreliable/false alarms, and reduced reliability. From a maintenance perspective, these design issues result in more repairs and false/nuisance alarms.

A major fuel release is the greatest hazard in LNG buses. This may be a low-frequency, high-consequence event with possible cryogenic burns, ignition, and asphyxiation results. False or premature alarms are also hazardous because they may cause panic responses and expose passengers and operators to road hazards during and after bus evacuation.

7. FUELING

7.1 DESCRIPTION OF REFUELING PROCESSES

Fueling of LNG buses appears to be the least mature part of the system. Efficient, dry-break fuel transfer is the key issue. The three basic vehicle refueling nozzle systems in operation or under development are:

- Dual-line, dual-nozzle with one for liquid transfer and the other for vapor return.
- Dual-line, single-nozzle with one connector for liquid transfer and the other for vapor return.
- Single-line liquid fill into the top of the tank. This system requires lower temperature LNG storage to enable incoming LNG to condense natural gas vapor in the fill tank's vapor space. None of the facilities observed employed this technology.

Both sites visited used the dual-line, dual-nozzle system but had significantly different operating conditions and fuel transfer effectiveness. Significant differences in operating conditions include humidity and frequency of refueling operations. Increases in both of these factors promote frost build-up on the refueling nozzle, and consequential connection difficulties and loss of dry-breaks upon disconnection. Nozzle maintenance frequency may also affect the ability to achieve leak-free fuel transfer.

Figure 1-6 shows a schematic of the dual-line, dual-nozzle system. At the agency that more closely resembled commercial operations, the nozzles leaked. Ice build-up on the refueling nozzle is a primary cause of small LNG releases during refueling. At the agency with fewer LNG buses, dry-breaks were observed.

Preceding page blank

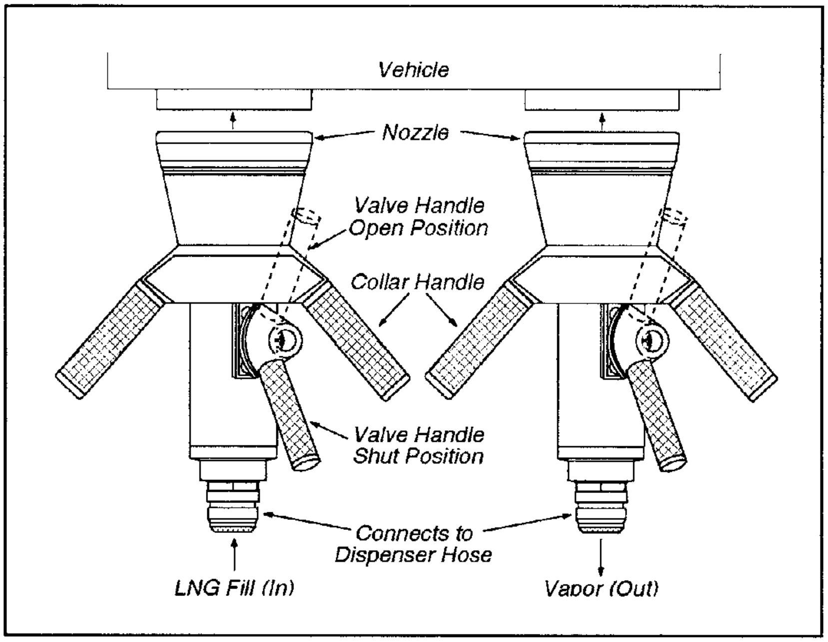

Figure 1-6. Parker Hannifin Nozzle System for Liquid Fill and Vapor Return

The LNG dispenser is similar in appearance to a gasoline dispenser, however, the LNG dispenser hose and nozzle are heavier, bulkier, and less flexible. Dispenser instrumentation includes pressure gauges, full-tank indicator light, system cool-down light, low-pressure detection light, and gas detector. Figure 1-7 shows an LNG dispenser.

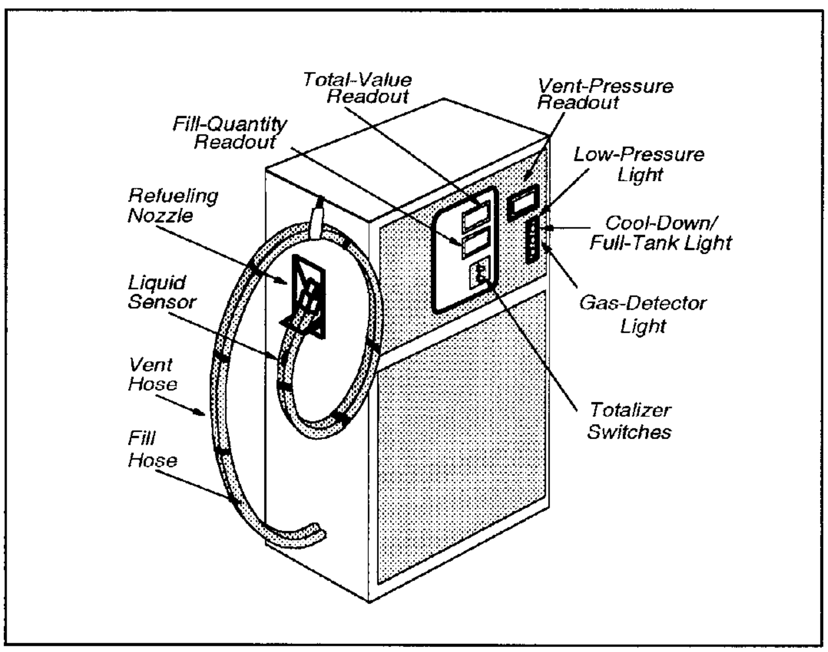

Figure 1-7. Fuel Dispenser for LNG Vehicles

The fueling operation consists of:

- Cooling-down of the liquid supply line. Cool-down is accomplished by attaching the liquid transfer hose nozzle to the LNG dispenser for recycling the vaporized fuel into the storage tank.

- Attaching the vapor recovery line to the vehicle's vapor recovery receptacle and the LNG supply line to the vehicle's refueling receptacle.

- Switching on the fuel meter and dispenser. The dispenser shuts off when the vapor recovery line senses liquid flow, indicating that the vehicle's LNG tank is full. (Fuel flow may be manually interrupted at any time.)

- After the dispenser switches off, disconnecting the nozzle from the vehicle and purging the remaining LNG from the line unless another bus is to be immediately refueled. (LNG left in the line will warm, expand, and trigger a pressure relief valve release.) Purged fuel is recovered into the storage tank or otherwise safely disposed.

One of the agencies had three LNG fueling facilities. Two were permanent and one was temporary. The temporary refueling facility used an LNG trailer that was protected by a cinder block wall on one side, and diking on the other three sides. The temporary facility was operated manually by a trained operator. The fueling operation was performed by first recirculating coolant with a small pump to cool down the system, and then attaching the fill and vent nozzles to the bus. The bus tank was initially and continuously vented to the atmosphere via lines that led to high and low vents behind the trailer. When filling was complete, the vent hoses were removed from the bus and vented to the atmosphere.

The permanent fueling stations were both recently constructed and currently maintained by a contractor. One had 22,000 gallons of storage capacity and the other 11,000 gallons of capacity. The tanks were located within concrete containments capable of holding the volume from a complete draining of one tank. Leaks within the containment area were sensed by cold detectors, which shut off the fueling operations but did not activate fire suppression. The dispenser cabinets were equipped with a methane leak detector that sounded an audible alarm, shut down the dispenser and closed system valves when 25 percent of the lower flammability level was detected. The automatic fire detection system used infrared and ultraviolet radiation detectors to sound alarms and activate a dry powder fire extinguishing system. Additional storage-tank cooling capability was provided by 2 water cannons located about 75 feet away from the station.

The Safety Team's observations of the fueling operations are summarized below:

- All the refueling stations except one were generally remote from other structures.

- Refuelers performed no other duties while refueling but might not devote complete attention to fueling operations.

- At one agency, the gas sensor closest to the refueling operation was blocked during fueling because it would activate too frequently.

- The computer-controlled refueling at the permanent station appeared designed to work with less operator attention. However, the operation was often not routine and frequent debugging was required.

- The manually-controlled fueling operations required venting fuel to the atmosphere. The automatic station was designed to vent LNG vapors from the vehicle tank into the station storage tank. About once a day, the storage tank was vented into the atmosphere.

- At one agency, protective attire (pants outside boots, long sleeves, protective apron and gloves, and face/eye protection) were prescribed by training documents. Despite this requirement, refuelers wore short sleeve shirts. (Other regulations were strictly adhered to.) At the other agency, the gas company refueling staff wore protective overalls, face shields, and gloves.

- Natural gas releases were observed from nozzles, hoses, and threaded connections at all stations at one of the agencies. Refueling operations run by the gas company at the other agency had no visible or measurable leaks.

- Some fueler discomfort with fuel and fueling systems was reported in interviews.

- Written procedures and safety guidance were not generally posted.

- Bus handlers smoked in the buses while moving around the lot. It was not clear whether these people were operators or refuelers. Management acknowledged problems with both groups disobeying smoking regulations.

- Equipment clearance and electrical standards were not followed at one facility. Non-sealed junction boxes (probably not energized at the time) were within 10 feet of the LNG fueling point.

7.2 FUEL TRANSFER HAZARDS

The primary safety issue relating to fueling/fuel transfer was that there are significant differences in the likelihood of LNG releases depending upon operating and climatological conditions. These conditions made the frequency of LNG leaks much less at one facility than at the other. Increases in LNG bus use in humid regions, and increases in the number of buses that are refueled in immediate succession, increases the probability of a significant LNG release during bus refueling. The following hazardous aspects of LNG fuel transfer were observed.

- Bulk Transfer of Fuel (Tanker To Storage) -- Some LNG vapor is lost in all bulk transfer activities. In many cases, liquid LNG escapes during the fuel transfer process. During an observed bulk transfer of LNG, fuel was released at the transfer hose connector points (both ends) during transfer-hose cool down (prior to fuel transfer), during fuel transfer at the threaded fittings of the receiving tank* and during disconnection.**

- Initial Tank Cool-Down -- Initial transfer of fuel to a storage vessel or fuel tank requires initial cool-down of the tank by the addition of fuel that immediately becomes vapor. During an observed LNG transfer from a delivery trailer to a "hot" temporary storage vessel, more than 15 percent of the LNG was lost as vapor vented to the atmosphere. The release was deliberate, expected, and semi-controlled. During the release, the LNG vapors were directed in an area of potential vehicle movement, i.e., potential sources of ignition.

---

* The fittings had to be tightened after cool-down to close the gap that developed during the cooling (uneven metal shrinking) process.

** The amount of gas released depended on how well the fuel-transfer line was purged.

- Bulk Storage of LNG -- LNG was transferred into a storage vessel that lost its vacuum insulation and continuously released LNG vapors through the pressure relief valve.

- Bus Fueling -- At one agency, all fueling events released LNG vapors, and most released droplets. Several fueling connections released streams of LNG. Similar releases occurred during the two- to three-minute hose cool-down. When excessive releases were noted, the operation was interrupted and temporary corrective measures were taken. Quantification of the released LNG was beyond the capabilities of the available equipment. Crude estimates were made using styrofoam cups to catch the dripping LNG. At the other agency, where two fueling operations were conducted each night, there were no fuel leaks during bus fueling.

- Pressure Relief/Boiloff Gas from Storage Tanks -- At one agency, storage tank boiloff gas was vented to the atmosphere through a 2-inch diameter pipe. At the other site (located on gas company property), the boiloff gas was directed into gas lines for collection and use.

The industry is aware of the shortcomings of the fuel transfer system and processes. Fuel and equipment suppliers are considering options to resolve the fuel leaks. The agency that used atmospheric venting was planning to convert its support fleet to CNG and use boiloff LNG vapors to help fuel these vehicles.

8. MAINTENANCE

Maintenance at both LNG agencies took place in the general maintenance facilities designed for diesel buses. They were not re-designed to meet NFPA 52 or draft NFPA 57 recommended guidelines and contained ignition sources, including open flame heaters.

Each facility employed some risk reduction strategies before and after admission into the maintenance facility. Each assured that there were no LNG leaks and periodically monitored the LNG pressure gauges on the bus. Each facility relied on the on-board gas detectors for gas leak warnings. At the time of the visits, there were no gas leak detectors installed in the maintenance facilities. However, each agency had plans to install the detectors.

8.1 OBSERVATIONS OF MAINTENANCE PROCEDURES

Safety team observations of the maintenance-related operations are summarized below:

- All bus maintenance was performed indoors in buildings without gas detection. Each agency had on-board gas sensors.

- At one agency, pits were used for under-chassis work. The equipment in the pits below the buses was spark-free. The other agency used lifts but made no effort to spark-proof equipment around the lift. A suspended ceiling was removed, following the recommendation of the fire marshall, to prevent the accumulation of natural gas between the ceiling levels.

- At one agency, only trained mechanics were used for LNG system-related maintenance. As new LNG buses were brought on-line, more mechanics were trained in LNG system maintenance. At the other agency, less emphasis was put on training due to the experimental nature of the LNG activities. However, the mechanics selected to work on the LNG system were those with some experience on these systems.

- Engine manufacturers were responsive to LNG-related issues and provided on-site personnel to assist in LNG-related engine maintenance.

- Component manufacturer support varied by agency and by manufacturer. At one agency, manufacturers were available for assistance, redesign, and parts. At the other agency, some contractors were very responsive and others less capable and less effective.

- In both agencies the fueling equipment was maintained by a contractor. At one, the fueling equipment supplier was on site to provide support and maintenance. At the other, the gas supplier (local utility) fully owned, operated, and maintained all equipment related to LNG fueling. For the short-term, each organization planned to continue this practice.

- Buses in the maintenance facilities were not routinely de-fueled. The common practice was to rely on the holding time to guard against releases of natural gas.*

- For maintenance operations that required the LNG tanks to be de-fueled (e.g., repairing or replacing the cryogenic pump), a layer of LNG remained on the bottom of the tank. This layer remained because the purge access-line was not low enough to remove all of the LNG. Depending on the fuel tank design and purge process, the remaining LNG was measurable in inches. However, in cases where LNG remained in the tank, a nitrogen overpressure was used to limit and dilute the escape of the natural gas vapors. The adequacy of this practice was unclear.

8.2 MAINTENANCE HAZARDS

The primary maintenance safety issue was the performance of maintenance activities in facilities that did not conform to the recommended NFPA 52 and draft NFPA 57 Standards. Of particular concern were operations that required breaching the integrity of the LNG fuel system. Both agencies understood the need to upgrade their facilities and were aware of the NFPA-recommended guidelines. Each had plans to make facility safety improvements.

At one agency, a strategic decision was made to focus on vehicle and training safety ahead of maintenance facility redesign. At the other agency, the decision not to upgrade the maintenance

---

* Holding time is the amount of time LNG can be stored in a tank, from the last time of operation (i.e., relief of pressure in the tank via fuel use/removal) to the time when the continuously formed LNG boiloff gas reaches the pressure limits set for the tank.

facilities was a financial one. With the acquisition of eight additional dedicated LNG buses to the existing two-bus fleet, the facility redesign decision would be re-examined.

In descending order of estimated risk, the safety-related maintenance issues at the transit agencies were:

- Maintenance Facility Design -- The maintenance facilities were designed for maintaining and servicing diesel buses. None of the maintenance facilities were converted to meet the recommended NFPA Standards (NFPA 52 and draft NFPA 57). All contained overhead and ground-level sources of ignition, no gas detectors, and ventilation capacity below NFPA recommendations, but upgrades were planned.

- Indoor Maintenance -- Indoor maintenance has greater risks associated with it than outdoor maintenance because released fuel can more easily collect and reach flammable concentrations. All observed maintenance activities were conducted indoors, including work on the LNG fuel system. Irregular monitoring tank pressure gages and time indoors at one agency, and scheduled monitoring at the other agency, may not be adequate due to inoperable pressure gages* and occasional loses in fuel tank insulation. The question of adequacy arose because of frequent component failures indoors, including inoperable pressure gauges and pressure relief valve releases.

- No Tagging or Lock-Out Procedures -- During maintenance the agencies did not isolate the LNG buses from other operations and did not employ tagging or lock-out procedures. This practice was not employed even when fuel-related work was being performed.

* Of the dozen or so buses that were observed during the fueling process one had an inoperable pressure gauge. Maintenance personnel said that the gauges required frequent maintenance.

9. LNG BUS STORAGE -- PARKING

LNG bus parking presents unique hazards in that fuel tanks are designed to release LNG vapors (i.e., boiloff gas). This may occur due to either the tank holding-time being exceeded, or reductions in tank insulating capacity. Assuming proper fuel tank insulation, fuel release through pressure relief valves during short-term indoor parking (i.e., shorter than the tank-holding time) is not likely. However, long-term parking presents unique hazards associated with the venting of boiloff gas. The risks associated with outdoor parking are lower than for indoor parking because LNG is likely to disperse more rapidly outside.

The LNG buses at the two agencies were parked outdoors. One agency parked its buses under a canopy (open on all sides), and the other in the yard without any side or overhead structures. Both agencies tried to avoid leaving LNG vehicles in the maintenance building overnight. No gas leaks in parked buses were observed. The hazards associated with parking of LNG vehicles are summarized below.*

The risk associated with short-term parking appeared to be low. The risks were due to the low probability of fuel system failure in a parked vehicle. Failure of the fuel system and concurrent failure of a gas detector are plausible, but highly unlikely. Collisions in parking facilities were commonly low-impact collisions not likely to compromise the integrity of the LNG fuel system.

The risks from long-term parking are the same as those from short-term parking, with the additional risk of venting LNG boiloff. Boiloff gas release can generally be predicted (based on tank-holding time) and controlled. The amount of gas released depends on several factors:

- The amount of liquid in the tank determined the amount of gas released at each venting. The more liquid in the tank, the less gas released, and vice versa.
- Setting the pressure relief valve to open at a relatively low pressure increased the likelihood and amount of gas released.
- Setting the pressure relief valve opening and closing points too close together increased the likelihood of gas release.

---

* Gas Research Institute, *Introduction To LNG Vehicle Safety*, GRI 992/0465, Chicago, Il, March 1994, Chapter 6.

After boiloff gas relief, the remaining LNG in the tank would build pressure and vent when the holding time was again reached. Ideally, pressure relief valves on parked LNG buses should be connected to discharge lines that ensured safe venting or collection of boiloff gas. This was particularly important for vehicles parked indoors.

10. SPECIAL CONCERNS

This section discusses special concerns in LNG bus use including odorization, asphyxiation, passenger compartment methane detectors, and continuing issues.

10.1 ODORIZATION

LNG vapor is odorless and colorless. For this reason the industry has been considering the use of an odorant in LNG. An odorant was used in vehicular applications by San Diego Gas and Electric in the 1970's, and was used at one of the LNG bus facilities observed in this study. Although the LNG odorant could be smelled at these facilities, the effectiveness of the odorant under all leak conditions has not been tested. Theoretical concerns about LNG odorant effectiveness stem from the normal solidification and precipitation of odorants at cryogenic temperatures (this is why odorants are removed prior to natural gas liquefaction). Rigorous testing of odorant effectiveness in liquid leaks, uniform odorant distribution in LNG, and the possibility of frozen odorant crystals may present fuel flow problems that have not yet occurred.

At the bus site that odorized LNG, the staff claimed that the LNG had an odor from the odorant that was left in during liquefaction. No odor was detected at the refueling station, primarily because no gas leaks were detected. However, in the maintenance facility, the end of the fuel tanks that contained the tubing, valve, and gauge connections had the common natural gas odor, even though there were no gas leaks detected (two measuring devices indicated no leaks). The agency staff explained that the odor was due to the residual odorant oil left on the fuel system from previous leaks. The agency did not report any adverse effect on the passengers or the agency staff.

The other LNG site visited did not use odorized LNG and had no plans for odorization. Reasons for not pursuing LNG odorization included effectiveness, consistency in signalling leaks, residual odors, and redundancy with the existing gas detector-based alarm system. Another reason was that the presence of an odorant would increase the anxiety of the staff, particularly the refuelers, who worked nozzles that frequently leaked.

10.2 ASPHYXIATION

At the agency that used no odorant there was concern regarding asphyxiation in the maintenance bays, where pits are used to access under-the-chassis components, including the LNG fuel system. Because methane detectors were commonly disabled during fuel-system work, in the event of an LNG leak, there may be no warning of hazardous conditions. The agency was alerted to this possibility and was advised to review this and similar practices.

At the facility using odorized LNG and bus lifts in the maintenance bays, the possibility of asphyxiation was greatly reduced. This was because the odorant, if effective, could act as a warning, and because there is greater air movement in the work area under buses on lifts than in pits.

10.3 PASSENGER COMPARTMENT METHANE DETECTORS

Methane detectors are recommended for indoor natural gas vehicle operations (NFPA 52). In draft form, NFPA 57 recommends the installation of on-board methane detectors. However, there are no guidelines for the use of methane detectors in passenger compartments of transit buses. The need for gas detectors in passenger compartments is controversial. Arguments against placement of gas detectors in passenger compartments include the following:

- The passenger compartment is isolated from the LNG system by a gas-tight (caulked) floor structure, thus it is unlikely that detectors in this area would ever be exposed to LNG vapors.
- Other on-board methane detectors would detect LNG vapors before detectors in the passenger compartment.
- There is a possibility of false alarms that could create hazardous situations for passengers (disembarking the bus, removal of disabled passengers, etc.).

At one agency, methane detectors were installed on some LNG buses for a test. The test indicated that it was more desirable to omit passenger compartment methane sensing devices due to numerous false alarms. The causes for false alarms were not confirmed, but operators claimed that alarms were set off by temporarily stopping over sewage drains, and passenger odors such as perfumes and colognes.

10.4 CONTINUING ISSUES

Key continuing issues for LNG bus operations that have controversial or unclear methods of address include the following:

- Optimal location and mounting of the fuel tanks and fuel lines to minimize the probability of fuel system damage during impact.
- Hazard detection system design and placement for optimization of fuel release detection without excessive false alarms. This includes the need for detector placement on-board buses and in maintenance, refueling, and parking facilities.
- Refueling technology that provides minimal fuel release during refueling, and dry-breaks upon refueling nozzle disconnection.
- Conditions that require bus defueling, e.g., specific maintenance and repair procedures, tanks with reduced insulating capacity, etc.
- Conditions that require the collection of boiloff gas from storage vessels and vehicle fuel tanks.
- The need for odorization of LNG to provide detection of fuel releases regardless of the operational status of hazard detectors.

11. SAFETY PROGRAMS

All transit agencies have a safety program, a safety officer, and some form of safety effectiveness training. Safety programs are required to ensure the safety of personnel, protect property, and meet facility performance requirements. Safety programs have reacted in a responsive and proactive manner when new and unfamiliar technologies are introduced (e.g., chair lifts).

Formal standardized safety program recommendations specifically for LNG-fueled vehicles do not exist. The closest reference to safety programs appears in the Draft NFPA 57, which recommends periodic inspection of equipment, such as LNG storage vessels, flexible hoses, and fire extinguishers. Some LNG safety publications exist that are specifically designed for agency use or could be readily adopted for this purpose. Among these are the Federal Transit Administration's *LNG Safety Training Manual*, GRI's *Introduction To LNG Vehicle Safety*, and a variety of LNG safety training materials developed or adopted by the Houston Metropolitan Transit Authority. These materials are readily available to organizations on request.

At one agency, the bulk of formal training was provided by giving basic information to selected staff members. Also, as buses were added, the need for developing both an effective emergency response plan and an effective emergency response infrastructure increased. At the other agency, an aggressive, structured program was implemented to train all of the staff. Based on the site visits and on information provided by the interviewees, a preliminary observation as to the effectiveness of the latter safety program is reviewed below.

11.1 OBSERVATIONS OF EMERGENCY PREPAREDNESS

Emergency plans at one agency included attempts at cultivating an effective response team to address both on-site and off-site emergencies. However, the safety team felt that more was needed to cultivate and maintain an effective emergency response infrastructure.

Emergency preparedness was reviewed on several levels. All comments referred to program status at the time of site visits.

- Staff Emergency Response Training and Procedure Development -- Operations and maintenance personnel were not trained to respond to severe emergencies and safety officials had no severe emergency response procedures. The training officials at one agency considered some severe accident scenarios for inclusion into the training curriculum but no specific procedures were developed.

- Availability of Emergency Response Teams -- Fire, police, and medical response teams were not effectively prepared to handle site and on-road hazards. There were no emergency response training exercises. Site management and staff felt that they would not receive the appropriate response from the above-listed organizations during emergencies.

- Usage of Surveillance Equipment -- No surveillance equipment was used to assist in LNG-related safety compliance. However, management was aware through other means of some safety-related, non-compliance issues, particularly smoking in areas designated as "no smoking" areas. The visiting team observed a bus operator smoking in the bus as it rode by the LNG refueling station and mechanics smoking in the repair areas. The agency was addressing the issue and was considering prohibiting smoking at all sites.

More can be done to develop an effective emergency response plan and improve the emergency response infrastructure, including the training of off-site personnel. These steps include development and dissemination of site-specific emergency response plans that establish clear and specific accident mitigation procedures, assignment of responsibilities, coordinated training, schedules and procedures for maintaining safety equipment, and familiarization with on-site and off-site hazards.

11.2 ROAD-EMERGENCY PLANNING

The emergency response plans should address responses for LNG leaks on the road, including issues such as:

- Conditions for evacuation (e.g., should bus passengers evacuate through an LNG cloud that covers the exit doors? An LNG puddle? An LNG spray?).

- Procedures for handling injuries and the disabled in a hazardous environment (e.g., under what conditions should injured people be moved from a vehicle that leaks LNG?).

Clearly, all possible details for accident situations cannot be addressed in even the most comprehensive safety programs. Ultimately, appropriate on-the-road emergency responses will rest on the judgment of the vehicle operator, dispatcher, and the emergency response team. This accentuates the importance of well-trained drivers.

12. MANAGEMENT AND SAFETY AWARENESS

12.1 FACTORS AFFECTING SAFETY

Management commitment to LNG seems to set the level and effectiveness of LNG-related safety activities. At one facility, the management was totally committed to LNG and to ensuring safety. At the other facility, management was experimenting with the fuel and was not ready to commit all needed resources.

Other factors that influenced the observed absolute and relative levels of safety at the two facilities are:

- The Status of LNG Use at the Agency -- At both facilities, safety address lagged behind LNG bus adoption and operation. In the allocation of limited funds, LNG buses and the fueling infrastructure were given priority over training and safety.

- Financial Ability -- At the time these agencies were adopting LNG no training materials and safety guidelines were available. At one agency, a costly effort was undertaken to develop needed training material.

- Safety Experience -- At one site, safety training was significantly intensified only after two incidents resulted in property damage. These incidents exemplified the need for effective training to avoid future property losses, injuries, and to develop a level of confidence and cooperation needed from the staff.

12.2 INTEGRATION

The integration of a developing LNG program requires significant input from management and safety personnel. One agency specifically assigned full-time individuals to ensure that the proper level of LNG safety was achieved. Based on observations of LNG facilities, programs with accessible managers and safety personnel were significantly more successful than programs without them.

Both agencies tried to integrate LNG buses into existing diesel fleets. At one agency, LNG buses were introduced at three facilities and fully integrated in the parking, servicing, and maintenance scheme of the agency. The only difference between an LNG and a diesel bus was the fueling process and a few preventive and corrective maintenance items. All buses used the same facilities for maintenance, operations, and storage. At the other agency, the buses were treated as experimental vehicles.

Based on observations of CNG and LNG operations, complete integration appears to be the more successful approach to operations. However, it needs to be performed with attention to safety.

12.3 LNG PROGRAM DEFINITION

An LNG program can either be carried out as an experimental program or as a fully operational portion of a transit system. An experimental program is characterized by a few buses (<10), special routes, reduced operational requirements, increased management and safety attention on a per bus basis, and some degree of separation from the normal line operations. In a fully operational program, the LNG buses are integrated into the fleet. The buses would be expected to perform regular duties and routes. The line managers responsible for normal operations would also be responsible for the operations and maintenance of the LNG buses.

13. TRAINING

Draft NFPA 57 recommends LNG handling and operation training for all employees who work with LNG. Also, a recent GRI report lists the likely training requirements of personnel by function. These are generally applicable to transit organizations and are listed in Table 1-1 as a guideline. As a practical matter, all personnel handling LNG should be trained in proper handling and operating procedures.

Table 1-1. Personnel Training

Job Category	Training
Vehicle operators (drivers)	LNG characteristics, vehicle operation, vehicle-specific emergency responses
Maintenance engineers	LNG characteristics, maintenance and repair safety and emergency response, vehicle and site-specific emergency responses
Dispatchers	LNG characteristics, general emergency responses
Parking attendants	LNG characteristics, general emergency responses
Towing	LNG characteristics, vehicle-specific emergency responses
Refueling	LNG characteristics, refueling safety and emergency responses, site-specific emergency responses
On-site first aid	LNG characteristics, general and cryogenic burn first aid
Security	LNG characteristics, general emergency responses
Facility and vehicle safety inspectors	LNG characteristics, operation, refueling, maintenance and repair safety, safety equipment (e.g., fire extinguisher, hazard detectors, and ventilation equipment), operation and maintenance, vehicle and site-specific emergency responses
Shop management	All of the above

13.1 PERSONNEL SELECTED FOR TRAINING

At one site, personnel including approximately 20 mechanics and more than 90 operators directly involved in handling LNG systems or the LNG vehicle received training. The large majority of the operators received only a one-hour introductory training course. A few others received more complete instruction and more extensive training. The night-shift mechanics were not trained and were not expected to handle LNG.

At the other agency, selective training of personnel was employed until a minor LNG-related accident occurred in one of the maintenance facilities. The accident caused the agency's management to embark on an aggressive training program to include all transit personnel who might need to handle any LNG equipment. Training was tracked on a computerized tracking system. The training and training materials were well prepared and effective.

13.2 TRAINING CLASSES/MATERIALS/TRAINERS

At one agency site, the training was provided by on-site safety personnel, the local natural gas utility (the supplier of LNG), and the system suppliers. The training material was composed primarily of technical manuals and basic LNG information. A specific assessment was provided of the difference in the quality of the technical manuals from suppliers.

At the other agency, training was formalized and well organized. It was evident that a considerable commitment was made to ensure that adequate training was provided. The classes were structured to provide basic LNG training to all personnel. The introductory class included LNG safety demonstrations by a safety expert. Subsequent classes were designed by job categories to meet the operational needs of the trainee. The materials were effective and contained recent information. Much of the training information was developed by the agency safety staff based on its observations and information in the general literature. Overall training effectiveness was very good. In response to inquiries on how to make the training more effective, the operators, maintenance staff, and fueling personnel suggested the following:

- Smaller training classes;
- More hands-on training;
- Feed-back loop needed from staff to trainers to communicate issues or to propose new/better solutions;
- Training material updates to deal with new systems and configurations;
- Training effectiveness measurement; and
- Refresher training.

13.3 CERTIFICATION

No certification requirements exist for the various LNG transit vehicle operations (fueling, maintenance, operations). As the use of LNG expands, states and localities may require certifications for some critical labor categories, including maintenance personnel, refueling personnel, medics, firefighters, safety personnel, trainers, and others.

At one of the operating LNG agencies, a state requirement existed for maintenance mechanics working with CNG. This requirement was extended to LNG. While CNG certification indicated knowledge in CNG, which was directly relevant to the CNG and NG parts of the fuel system, it was only minimally relevant to the cryogenic parts of the LNG system. The safety team considered this certification helpful but insufficient. There were no certification requirements at the other agency.

In addition to the certification of transit personnel, requirements for certification may extend to certain cryogenic equipment. These requirements may include the certification of fuel tanks, bulk storage vessels, cryogenic subsystems (pumps, valves, fire extinguishing equipment, etc.). Equipment certification may be in accordance with some national organization, such as the U.S. Department of Transportation, American Gas Association, or ANSI.

13.4 REFRESHER SCHEDULE

The importance of providing refresher courses was discussed with the staff and trainers at both agencies. There was a consensus that the staff needed or would need refresher training. This need arose from the following set of circumstances:

- Initial Time Lapse -- It might be months between training and the first time the trainee was able to apply the knowledge. This was too long a period to maintain effective theoretical knowledge without the reinforcement of practical applications. This was an issue at both agencies for all job categories.

- Time Gap -- Much of the knowledge from training was infrequently applied. This was true at both sites and affected operators and maintenance personnel. Fueling personnel were not affected because of the nature of their job. (Also, at one site, fueling was performed by the gas company personnel. Assessment of their training effectiveness was beyond the scope of this task.)

- Multitude of System Configurations -- Due to procurement requirements, the agencies were forced to acquire buses from the lowest bidders. At different times this resulted in different vehicles and different LNG system configurations. At one site, trainees were not confident that they understood all types of vehicle/LNG system configurations.

- System Variability -- Further complicating the vehicle/LNG system configuration issues were post-delivery changes to some systems. These changes were poorly documented and the documentation was not available on the vehicle.

- Technology Developments and Experience -- LNG technology and experience was developing at a fast pace.

The suggested time interval between refresher courses varied widely, and no attempt was made by the safety team to define a set time interval. However, those that dealt with the issue of initial time lapse and time gap between opportunities to practice concluded that three to six months was too long. At the time of the safety team's visit, one agency was addressing retraining, including frequency, staff selection, and content.

13.5 EXTERNAL EMERGENCY RESPONSE PERSONNEL

The training of External Emergency Response Personnel (EERP) was minimal. The only involvement with EERP was with the local fire marshal. These interactions related to codes and the future installation of methane detectors. Also, information was made available to the fire marshall on the fuel stored at the site. No training was conducted with any member of the EERP, and no plans were revealed to do so. One agency relied on the capabilities of the surrounding fire departments to handle fuel-related accidents. While this might be reasonable based on the experience in the city, operators indicated that they had no confidence that the responding fire department would know what to expect at the site and how to respond to an LNG emergency.

Similarly, there was an absence of coordination in EERP in police departments, hazmat units, and the medical community. At one agency, the safety officials were not confident that the local hazmat unit was aware of emergency practices relating to LNG, even though there was an LNG peak-shaving plant in the city.

13.6 EMERGENCY RESPONSE TRAINING

Emergency response training for on-site and off-site emergencies needs to be differentiated. In both types of emergencies the same types of hazards exist. In on-site emergencies, however, the physical environment, the response team responsibilities, types of event, and availability of equipment, among other issues, are relatively well-defined and predictable. In off-site emergencies, such as those that can occur anywhere on the bus route or along the LNG delivery route, these factors are ill-defined and unpredictable.

The site surveys indicated that the staff was generally better trained and better able to understand on-site emergency response procedures. This was primarily due to the ability to more readily specify the hazards and the mitigating procedures. On the other hand, knowing procedures and possessing the means of implementing them were not the same thing. At one site, the procedure to respond to an LNG fire was known. However, attendants did not know where to find the key to turn on the water spray for cooling the LNG storage tank designed to keep the tanks cooled during general fire.

For off-site emergencies it was more difficult for the trainers to prepare standardized procedures. In general, the operators were trained to respond to simple emergencies, such as a detected LNG leak. However, they were less sure of the proper procedure for complex scenarios such as an LNG cloud near the emergency exits or what to do with injured or disabled passengers. There are no established industry procedures for these types of complex accidents, and these may exceed normally acceptable levels of training.

14. CONCLUSIONS

To date, the survey indicates that the safety record of LNG facilities is satisfactory. No incidents have occurred that caused a loss of life or cost a large amount of money at a transit facility. However, this record is based on a statistically small base. The number of LNG buses and facilities is growing rapidly. The fact that no serious events have occurred is not statistical evidence that one will not occur in the future.

The design characteristic that causes the highest risk is the use of open flame space heaters in buildings where LNG buses are maintained, serviced, or stored. LNG will occasionally be released and a nearby, operating space heater is an ideal ignition source.

While space heaters pose a major safety concern, the overall problem is the lack of clear guidance, standards or criteria for an LNG vehicle maintenance facility. Both agencies surveyed had indoor maintenance, and neither defueled buses before they entered the facility for repair or maintenance. In some cases, methane sensors were disconnected and buses with LNG in the tanks were maintained. Despite the obvious potential for a major accident, there were no standards or regulations suggesting or requiring different or safer procedures. Similar deficiencies existed in other areas, such as operator familiarity with shutoff valves, fuel leakage, and emergency preparedness.

A programmatic commitment to safe operation is required for a successful LNG program. During the design phase, an analysis of hazards should be performed prior to embarking on an LNG program. From this assessment, hazards can be systematically mitigated by design modifications and procedural steps. These procedures should include operational procedures for the equipment, safety procedures that are robust enough to cover all of the contingencies of LNG use, and emergency procedures that would involve local public officials. Following procedure development, management should incorporate both initial and refresher training programs, and continually evaluate the field performance of procedures.

SECTION II

ALTERNATIVE FUELS IN TRANSIT OPERATIONS: LIQUEFIED NATURAL GAS SITE SURVEYS

Battelle - Transportation Division
Columbus, OH

Kevin Chandler
Norman Malcosky
Michael J. Murphy

Gannett Fleming, Inc.
Harrisburg, PA

Robert Schmelz

Technology & Management Systems, Inc.
Burlington, MA

Phani K. Raj

1. INTRODUCTION

An increasing need exists to more fully understand the modifications in transit facilities and transit operations required for the safe and effective use of alternative fuels. To provide an understanding of these requirements, the Volpe National Transportation Systems Center (Volpe Center) has established a research program for the Federal Transit Administration (FTA). With an increasing number of transit systems operating alternative fuel fleets in response to urban air quality standards, this program is intended to provide information needed for the safe and effective use of alternative fuels in transit.

This report presents an account of surveys conducted at two sites using Liquefied Natural Gas (LNG) as an alternative fuel for transit buses and other vehicles. LNG is natural gas that is stored on a vehicle as a cryogenic (very low temperature) liquid. This liquid is only slightly pressurized, at pressures less than 2 MPa (300 psi) and at temperatures as low as -161 C (-258 F). Upon warming to ambient temperatures, it behaves as natural gas in bus engines and facilities.

Natural gas from LNG is comprised principally of methane, with minor amounts of ethane, propane, and butane. Both carbon dioxide and nitrogen are removed by the liquefication process. Natural gas from LNG itself is colorless and tasteless, and, to date, is unodorized and, consequently, not detectable. Electronic combustible gas sensors are needed to detect it. Natural gas at normal temperature and pressure has a density relative to air of only about 0.6, meaning that natural gas is considerably lighter than air. When mixed with air (at from 5 to 15 percent by volume) and exposed to an ignition source, the fuel will burn and, if the mixture is fully or partially confined, an explosion will occur.

1.1 METHODOLOGY

The survey method included the following procedures: site visits lasting several days; intensive interviews with transit personnel at various levels in each organization; observation of facilities and operational procedures for compressing, dispensing, and otherwise handling LNG in transit operations; and on-site measurements for ambient levels of LNG. The survey team consisted of Battelle, Gannett Fleming, and Technology & Management Systems.

1.2 FINDINGS

The surveys revealed that, in general, LNG buses can be used in regular revenue service and have demonstrated a range similar to that of diesel powered vehicles. However, as an integral part of the site assessments, each aspect of the LNG operations at a given site was compared with the operations of other LNG transit sites, as well as with national standards and safety engineering practice.

No one site was found to be best in all aspects of LNG operations. For example, in some facilities ignition sources were found near the ceiling or in areas where natural gas could be present. However, other facilities have successfully eliminated these ignition sources or implemented a strategy of methane sensor systems to warn of gas accumulation, along with electrical system controls, to automatically disable ignition sources and ventilation exhaust to purge ceiling areas of fuel.

Workers involved with LNG operations generally appeared highly motivated and interested in safety, but sites varied widely in the type of training given, the amount of LNG safety information available on the shop floor, and the amount of objective knowledge attained. Although comprehensive information addressing all of the issues related to the processes of fueling, operating, maintaining, and responding to emergencies should be available in the work place, several cases were found where written procedures for certain LNG operations were not easily accessible. Sometimes comprehensive training and procedures manuals existed, but they were not fully appropriate to the intended audience. At other locations, information on LNG operating procedures was available, but emergency procedures for drivers or mechanics were not available. On the other hand, one location had a special section in the front of the training materials (identified with a red tab) that had a summary of first aid and emergency procedures.

The surveys also included an examination of the occupational hygiene aspects of LNG use. With a few exceptions, such as cryogenic fuel leakage from fueling nozzles and the need for more careful consideration of possible asphyxiation hazards, the work environment at the facilities was quite good.

1.3 REQUIREMENTS FOR SAFE LNG OPERATION

Based on surveys of the two sites, the following safety issues are of the greatest significance in planning and operating LNG transit systems:

- Training of operating staff. Safe working conditions are best secured by providing operating staff with a clear understanding of the properties of LNG fuel and the proper procedures to follow when using or maintaining LNG vehicles and equipment. Both safety and operational information should be available in a form transit employees readily understand at appropriate locations in the work place. Formal training updates should be given periodically and a consistent procedure established for experienced personnel to share their LNG fuel experiences with less experienced staff.

- Control of strong ignition sources. Strong ignition sources should be removed from areas where LNG buses are stored, maintained, or fueled. Of primary concern are strong ignition sources such as open-flame gas heaters, motor starters on fans and door openers, and other spark-producing electrical equipment (electric bug zappers, etc.).

- Alarms and other warning systems. Warning systems consisting of combustible gas sensors and an alarm system should be installed in all LNG facilities. These systems can warn of potential hazards, because personnel cannot by smell detect an LNG fuel buildup. They are also effective when personnel are not present. These warning systems can be configured to independently increase ventilation rates to more quickly remove any gas buildup and to disable potential ignition sources. Maintenance and testing programs for such alarm systems should be implemented.

- Facility ventilation. Preventing gas buildups in LNG facilities is one of the primary methods of reducing potential fire hazards. Facility ventilation requirements are significantly different for LNG vehicles than for diesel- or gasoline-fueled vehicles, and ventilating low areas (such as maintenance pits), ceilings, and high areas is especially important.

1.4 REMAINING ISSUES AND TOPICS

Several relevant questions outside the scope of this study have yet to be fully resolved, including the complex issue of code coverage and interpretation, appropriate building and equipment standards, and the best methods for training and certifying transit employees in the use of LNG as a transit fuel. In addition, the following technical issues should be resolved as the results of additional safety research become available:

- More information is needed on the successful deployment and use of combustible gas detectors within transit facilities, including the number and location of detectors and periodic calibration requirements. Moreover, detector response time must be consistent with the time required to implement remedial actions.

- The use of such detectors for LNG is complicated by the change in density in going from cold LNG vapors, which are heavier than air, to warm natural gas, which is lighter than air.

- Because methane is a formaldehyde precursor, formaldehyde buildup in bus storage facilities during morning pull-out should be monitored as the LNG fleet size increases within a given facility.

- A system safety and hazard assessment analysis needs to be performed to more clearly identify the relative safety implications of the choice of fuel tank location on the bus. This safety assessment should include the piping and valve associated with the fuel tanks and consider movement of the fuel vapor cloud if a leak develops in the cryogenic fuel system.

1.5 REPORT CONTENT

This report presents an assessment of current practice in LNG transit programs and a summary of basic principles and general recommendations for its safe operation. The recommendations are based on information gathered and lessons learned from the transit sites surveyed, as well as on prevailing practices in industrial engineering, safety, and risk management. The report includes discussion and recommendations on LNG facility design, fueling, maintenance, vehicle storage, buses, operations, special concerns, emergency planning, management and safety awareness, and training.

2. LNG USE IN TRANSIT

2.1 DEMONSTRATION PROGRAMS

The FTA has encouraged the transit industry to experiment with alternative fuels by establishing the Clean Air Program (CAP) and the Alternative Fuels Initiative (AFI). Under this initiative, financial grants were provided to transit agencies to test a wide variety of alternative fuels. These grants were made to purchase alternative fuel buses and, when necessary, modify or install new fueling facilities, maintenance areas, and storage areas. LNG is envisioned as becoming one of the more popular alternative fuels with the transit agencies. Several demonstrations of the LNG technology across the U.S. are currently receiving federal funding.

2.2 CONVERSION TO LNG

LNG buses are 500 to 1500 pounds heavier (depending on length and number of fuel tanks) than diesel buses of the same length. Adding LNG buses to some routes, therefore, may be difficult due to weight restrictions.

As the transit industry (including suppliers of equipment and operators) gains experience in the use of LNG buses, the commitment to LNG as an alternative fuel becomes far less difficult. Early AFI programs faced the compound problems of newly developed engines and fuel systems (which affected vehicle reliability and availability), inadequate employee training materials, and facilities designed for traditional fuels. The LNG support industry has developed rapidly in the last two years. Currently, several major engineering equipment firms can supply the expertise and hardware necessary to convert a transit facility to LNG. The past experiences of these firms are important, and a transit company considering converting to LNG should secure the services of companies skilled in this area.

2.3 LNG FUELING FACILITY

The major components of an LNG fueling and fuel storage facility are shown in Figure 2-1, which illustrates the general way LNG is received from a fuel supplier, stored in a large (10,000- to 30,000-gallon) stationary cryogenic storage tank, and dispensed by a cryogenic pump or a pressure transfer technique to the fuel containers on transit buses. All transit agencies

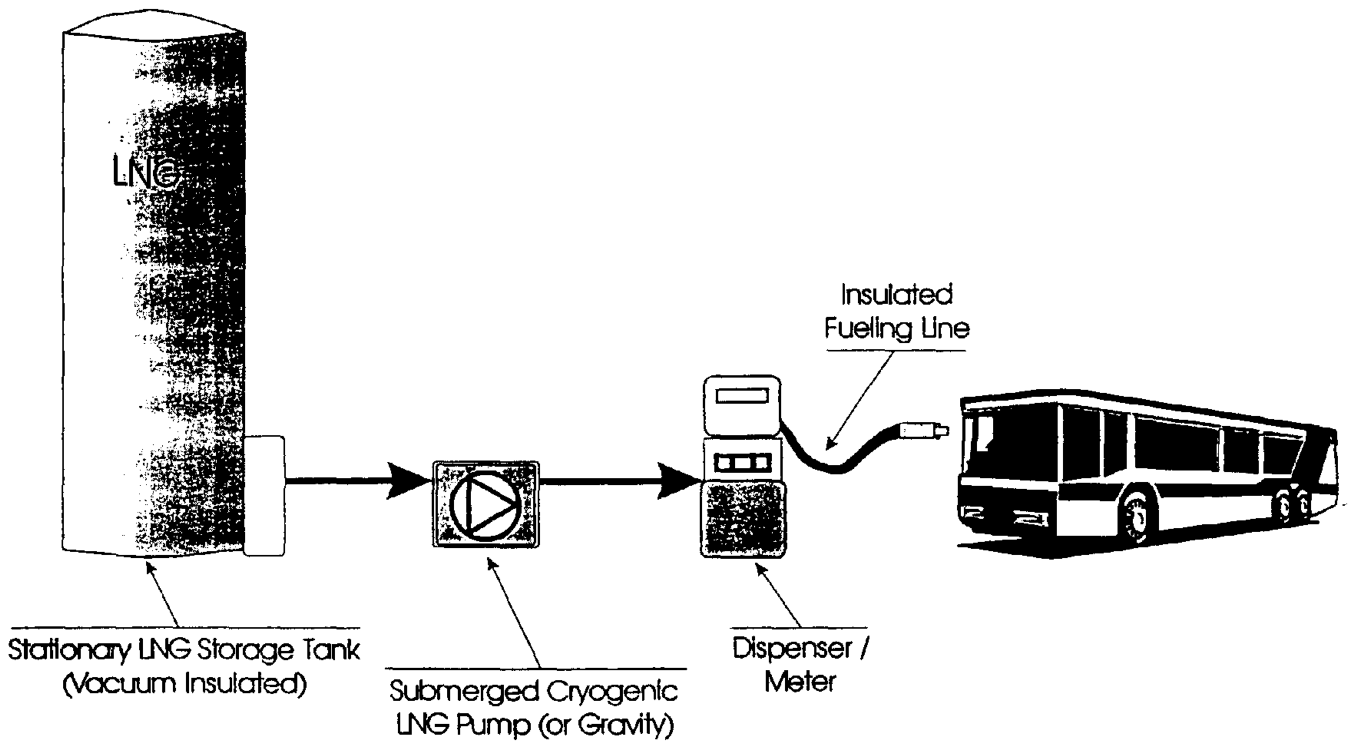

Figure 2-1. Schematic of LNG Fueling Facility

demonstrating LNG utilize a fueling strategy similar to Figure 2-1 that can fuel a bus in approximately 5 minutes. The cryogenic liquid is fed through a fuel meter and dispenser and, finally, through an insulated hose to the fueling nozzle.

2.4 MAJOR OPTIONS AND DECISION POINTS FOR PLANNING AN LNG TRANSIT SYSTEM

Any alternative fuel presents a safety challenge to the transit system that uses it, as well as to local code officials. Building codes have not been rewritten to account for the range of alternative fuels now being used or considered for use by transit systems. This creates a dilemma for local fire marshals or local building code enforcement officials, who are the ultimate authorities for approving alternative fuel facility designs and operating plans. These officials should be involved, as early as possible, in the facility planning and design process to avoid unnecessary delays and the potential for misunderstanding. By involving local officials early, it is possible to provide education and documentation that addresses and reduces risks in facility planning and design, as well as to learn about local requirements and concerns.

Principal contacts that should be made when determining how an LNG transit operation should be implemented include:

- Consultants skilled in analyzing both the needs of transit operations and all alternative fuels. A comparison of several alternative fuel options with current diesel operation is often desirable.

- Architecture and engineering firms with previous experience with LNG facilities, fueling operations, and local codes and their enforcement.

- Local fire marshals.

- Fuel suppliers, which may include the local gas utility and wholesale producers.

Often an LNG program will include a demonstration or pilot phase in which five or ten buses are operated for several years. If the pilot program is successful or if mandates require a switch to an alternative fuel, a phase-in strategy must be formulated. The entire fleet conversion could take more than 15 years and require conversion or modification of all facilities, replacement of all principal vehicles, and operation of a "mixed" fuel fleet for a number of years.

3. PROPERTIES OF LIQUEFIED NATURAL GAS

3.1 PHYSICAL PROPERTIES

Natural gas from LNG is a mixture of several gases forming a fuel that can be used in homes for cooking and heating and can also be used to power most types of vehicles. Natural gas from LNG typically contains 85 to 99 percent methane with much smaller (zero to five percent) quantities of ethane and propane, and even smaller quantities of N_2 and butane. Pentane, hexane, CO_2, and water vapor are removed from the natural gas during the liquefication process.

3.2 DISPERSAL AND IGNITION

At normal ambient atmospheric temperature and pressure, natural gas is lighter than air and will rise to the ceiling if released indoors. This is quite unlike conventional liquid fuels such as gasoline, propane, and diesel, whose vapors are heavier than air and fall to the floor. This unique physical property causes concern because it is not addressed by current facility building codes.

Moreover, the dispersion behavior of natural gas from LNG released from a cryogenic fuel tank may be quite different from natural gas that escapes from a building's heating supply pipe at relative low pressure. The gas emanating from the cryogenic fuel tank will be very cold and may be more dense than air. Such dense gas will disperse close to ground level for a significant duration and distance from the release point. Additional experimental tests simulating realistic LNG releases from a bus fuel tank should be conducted to explore the magnitude and extent of this effect. The results of these tests will affect the basic philosophy of LNG bus facility design and operation including the location of combustible gas detectors and the type of emergency response actions.

Natural gas burns only when the gas-to-air ratio is between 5 and 15 percent by volume. It has an ignition temperature of about 450 C, while gasoline ignites at about 300 C. The ignition energy of natural gas, like that of other hydrocarbons, is relatively low. For an optimum mixture and geometry, about 0.3 milliwatt-seconds (millijoules) of energy is required for ignition. Static discharges can easily generate several times this amount of energy.

4. LNG TRANSIT FACILITY DESIGN

At one LNG transit site, the design focused on reducing heat loss and minimizing system pressures. Staff at this site believed this approach served them well. For example, they tried to minimize the amount of piping associated with the station. They felt that using a tank trailer system imposed a discipline on the engineering efforts by limiting the physical space available for piping. Staff at this site also believed that LNG was a significant advance from CNG in technical sophistication. They hoped to use computers to make the procedural aspects of the fueler's task simpler.

One of the major factors used for assessing transit facility design was, as mentioned earlier, applicable codes and standards. At this time, no national, state, or local building codes exist that are specifically written for LNG transit fueling, maintenance, or storage facilities. The National Fire Protection Association (NFPA) 57 fire code, which is currently in draft form, will, when approved, cover LNG dispensing facilities, but will not cover vehicle maintenance or storage areas.

The most applicable codes to LNG design are the fire safety codes promulgated by the NFPA. In addition, certifications of equipment by the American Gas Association (AGA) apply but only with respect to gas dispensing equipment, fittings, etc. These codes are not specifically addressed because they are either an intrinsic part of equipment design or are incorporated by references in the NFPA codes. Specific NFPA codes that may be at least partially applicable include:

- NFPA 30A - Automotive and Marine Service Station Code;
- NFPA 52 - Compressed Natural Gas (CNG) Vehicular Fuel Systems;
- NFPA 54 - National Fuel Gas Code;
- NFPA 57 - LNG Vehicular Fuel Systems (Draft);
- NFPA 58 - LP - Gas Storage, Use;
- NFPA 59A - Standards for Production, Storage, and Handling of Liquefied Natural Gas (LNG);

- NFPA 69 - Explosion Prevention Systems;
- NFPA 70 - National Electrical Code;
- NFPA 88A - Parking Structures;
- NFPA 88B - Repair Garages;
- NFPA 91 - Exhaust Systems for Air Conveying of Materials;
- NFPA 497A - Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas; and
- NFPA 497M - Classification of Gases, Vapors, Dusts for Electrical Equipment in Hazardous Locations.

Although several of the codes listed above may not directly apply, information provided in these codes can be valuable during the evaluation of design issues for which no specific code exists. They also support design decisions based on engineering judgment. Because of possible design liability, many A&E firms consider it prudent to evaluate facilities based upon *conservative* interpretations of the codes they consider relevant, particularly when they lack extensive long-term implementation experience.

For transit LNG fueling facilities, the draft edition of the NFPA 57 fire code will cover equipment used for the storage and dispensing of LNG. Most sites followed the provisions of NFPA 57 for the design of the fuel storage and dispensing facility.

At this time no national, state, or local codes are specifically directed at LNG transit bus storage and maintenance facilities. Design engineers must interpret and apply current related codes. NFPA 88A and 88B are two such existing codes that could be used as a starting point. The difficulty is that 88A and 88B are directed toward gasoline, which has vapor that is always heavier than air, but do not reference vapors from LNG that may be either heavier or lighter than air. NFPA 70, as well as the provisions and examples of NFPA 497A, is also helpful for determining proper electrical classification.

Because not enough transit facilities have used LNG long enough to establish a long-term safety record for this fuel, a reasonable, responsible, and prudent philosophy should be used as the basis for a facility design that protects both life and property. Several design engineering strategies that are currently being used for facility modifications are reviewed in detail below.

4.1 DESIGN STRATEGIES

Four distinct schools of thought on the application of the NFPA codes to LNG facilities have been identified. This range of options is particularly significant when addressing the issue of modifying existing transit facilities to accept LNG-fueled vehicles. Although each of the four schools of thought has some validity (these are outlined below), surveys of LNG sites conducted by the authors of this report indicate that the fourth school now has the greatest currency. Engineering analysis made by these authors also indicates that the fourth school has the most relevance now while the LNG vehicle technology is so young. The other approaches may be more appropriate as their technology matures and designers and code officials have available a demonstrated track record of their successful implementation.

4.1.1 Complete Fuel Containment Approach

The first school of thought is based on an analogy to a comment in NFPA 58 code for propane, which says that propane-containing pipes and containers without valves, etc., do not require classified electrical systems. This school of thought assumes that the flammable gas (in this case LNG) is and always will be completely contained in pipes and tanks. Under this design strategy, conventional facilities would be adequate for both servicing and storing LNG buses (as is allowed for propane-powered vehicles). This strategy currently is being demonstrated at a major LNG transit agency. No problems have been reported and no major LNG fuel releases have been encountered in these facilities. However, the possibility of venting from LNG fuel tanks as well as the difficulties in making uniformly tight cryogenic connections raise questions about the rationale for this strategy.

4.1.2 Omnipresent Ignition Sources Approach

The second school of thought holds that although releases of natural gas may occur, ignition sources are normally present in these areas as an inevitable part of the operations. Therefore, classified electrical or explosion-proof systems (heating equipment, switches, and motors) need not be used because they would add nothing to safety.

4.1.3 <u>Strict Adherence to NFPA 70 Approach</u>

The third school of thought is that a strict interpretation of NFPA 70 should be followed. NFPA 70 designates as Class 1, Division 2, areas where a flammable gas that is normally contained could be accidentally released. For reference and comparison, an interpretation of NFPA 70 (the National Electrical Code), Articles 500 and 501, demonstrate the following:

- Article 500 of NFPA 70 defines atmospheres containing natural gas as Class 1, Group D, areas.

- Properties, uses, and tasks typically taking place or reasonably expected to take place in vehicle storage and vehicle maintenance areas dictate that they are Class 1, Division 2, areas as defined in Article 500 of NFPA 70, and that they are subject to the requirements, recommendations, and standards set forth in Article 501. Since each LNG bus has several pressure relief devices, an LNG fleet has numerous possible discharges into the space.

- This interpretation is amplified in NFPA 497A, which states that classified electrical is required if any pressure relief valve discharges are located within the area. Since each LNG bus has several pressure relief devices, an LNG fleet has numerous such discharges into any space where LNG buses are parked.

Clearly this third approach is conservative but is justified if the frequency of natural gas releases is, or is expected to be, relatively high.

4.1.4 <u>Modified NFPA 70 Approach</u>

The fourth approach modifies the strict interpretation of the third school to take into account some of the technical information available about the ignition process for flammable gases. This approach would require that "strong" or continuous ignition sources always be removed whereas certain "weak" and incidental ignition sources may remain. This approach has appeal because:

- The issue of major fuel releases within the facility would be addressed by a responsible plan.

- Current combustible gas sensor technology, it is believed, has sufficient capability and response time to provide shutdown of electrical equipment upon the accumulation of gas from minor leaks, provided the sensors are located strategically to sense, in a timely manner, methane vapors from an LNG leak.

- Expensive facility modifications, principally classified wiring and equipment, would be reserved to eliminate agents that are clearly significant ignition sources.

In this context, "strong" ignition sources are those that are sufficiently energetic to have a high probability to cause immediate ignition of a natural gas-air mixture. Examples are open pilot lights, operating gas- and oil-fired open-flame heaters, and high wattage or inductive load electrical contacts.

On the other hand, "weak" ignition sources include computers, telephones, exit lights, test equipment, and other low-wattage electrical devices.

The technical basis for this approach is the observation that though the minimum ignition energy for methane and other gases is quite low (about 0.25 milliwatt-seconds, or joules), the practical energy necessary for ignition in a less than optimum geometry is much higher. One study performed by Arthur D. Little for the Gas Research Institute[*] lists experimental results that show that only electrical contacts that carry a resistive load of 640 watts or more or activate motors 1/4 hp or greater will ignite natural gas clouds with a high probability, while lesser loads do not easily cause ignition in normal electrical contact geometries. As a practical matter, a factor of safety of two or three should be applied, leading to the conclusion that electrical contacts with a resistive load of less than 200 to 300 watts and motor-switching loads of less than 1/8 to 1/12 hp may be considered "weak" ignition sources.

Needless to say, this approach represents something of a compromise since there can be no guarantee that a weak ignition source cannot cause ignition unless that source has been certified as intrinsically safe. However, if these weak sources are not continuously present and this approach is coupled with a gas detection system and improved ventilation, the probability is high that a natural gas release or an LNG spill will be safely vented before causing ignition.

[*]D. J. Jeffreys, N. A. Moussa, R. N. Caron, and D. S. Allan, "Ignition Sources of LNG Vapor Clouds," GRI Report GRI-80/0108, January 1982.

Because of the desire to focus economic resources where the greatest safety benefit can be obtained, the discussion below of specific measures to take for LNG use generally follows this approach.

4.2 FUELING AREAS

4.2.1 General

Fueling areas should be subject to the requirements, recommendations, and standards set forth in the draft of NFPA 57 and NFPA 70, Article 514, but this does not mean that these are the only codes applicable to specific installations.

During connection, disconnection, and operation of the bus fueling nozzle, fuel can be released or leaked in the vicinity of the fueler (hostler). This can create an unsatisfactory and hazardous condition during both fueling and disconnect. Only fueling hardware and equipment that prevents this condition from occurring should be utilized.

4.2.2 Lightning

LNG fueling areas should be protected from lightning, especially when located in an area with high lightning risk. Grounding and bonding must be employed on all LNG equipment and fuel storage containers. NFPA 180 describes the specific measures required for proper lightning protection.

4.3 BUS STORAGE AND MAINTENANCE AREAS

4.3.1 Ventilation

Adequate ventilation should be provided for LNG facilities. All LNG fueling areas should be ventilated and should be capable of providing five to six air changes per hour (per NFPA 52 and 57) if a gas leak is detected. Ventilation systems should be integrated with facility gas detection systems.

In both storage and maintenance areas, only outdoor exhaust fans or fans with explosion-proof motors should be located near the buses. The system should be designed to prevent leaking gas from being carried deeper into the garage and becoming trapped in the roof system or floor pits, or migrating to other parts of the building. Ventilation is necessary in both high and low building locations for LNG fuel vapor removal.

4.3.2 Heating Systems

Gas fired make-up and heating units with open flames should be removed. Even though these units utilize nearly 100 percent outdoor air, the negative pressure on the intake to the unit could draw in gas if there are any holes or cracks into the ducts.

Surface temperatures of all heating equipment should be less than 450 C to eliminate hot-surface ignition problems. Exterior mounted heating equipment with heat reclamation may have to be "re-tuned" to provide lower surface temperatures on indoor parts. Direct-fired heaters should be replaced with indirect-fired units (hot water, steam, etc.) that do not create an ignition source.

4.3.3 Electrical Systems and Other Potential Ignition Sources

No strong or continuous ignition sources should be located near the ceiling or in close proximity to LNG vehicles. The examples in NFPA 497A, dealing with distances, should be used as a guide. Motors or switches installed near the ceiling and used to open doors or start fans should either be moved to the exterior of the building or be made explosion-proof. Special procedures may be needed for the use of overhead cranes because such use, of necessity, involves overhead sliding electrical contacts.

4.3.4 Leak Detection Equipment

Combustible gas detectors should be installed at the fueling station in both high and low positions and in maintenance and storage buildings. These detectors should be tied into an annunciation system that is continuously monitored on site, such as a vehicle dispatching area that is always staffed. An electric power control strategy may be part of the safety system, shutting down all potential electrical-system-based ignition sources if a fuel spill or gas release is noted by the detectors.

4.4 OPERATIONAL ISSUES

Fuel system leaks are inevitable in a transit operation involving large numbers of vehicles in revenue service. While LNG buses may be designed to satisfy a higher safety standard or currently receive more management attention than diesel buses, many aspects of LNG vehicle design have not yet gone through a full vehicle life cycle.

If an LNG leak does occur, it is essential that the leaking gas not contact an ignition source. While a combination of combustible gas detectors and increased ventilation can help keep flammable layers from lingering, these systems require time to respond and operate. In the presence of an ignition source, a flammable mixture ignites in only milliseconds. Therefore, if an ignition source is present directly over an LNG leak, and a plume of natural gas reaches the ignition source, the natural gas *will* ignite.

The only way to prevent such ignition is to remove ignition sources. This philosophy is consistent with the philosophy long applied to other fuels, such as gasoline, with heavier-than-air vapors, which prohibits any ignition sources at a level lower than the level of probable fuel vapor release. This same strategy would be followed in applying the "removal of strong ignition sources" school of thought to the interpretation of NFPA codes.

It is not reasonable to expect that mechanics will make all repairs involving LNG vehicle fuel systems outdoors far from required tools and parts, particularly at night or during inclement weather. Therefore, it is not adequate to address the issue of fuel release during fuel system maintenance or repairs by establishing a procedure requiring that all such repairs be performed outdoors.

Also, "No Smoking" signs should be located and enforced in the maintenance and fueling facilities, particularly in the pits where service operations may be conducted on the fuel system, as well as where LNG fueling is performed.

5. FUELING

The draft NFPA 57 specifies design criteria and equipment qualifications for storage and dispensing systems for LNG fuel. Although the code allows flexibility in equipment and dispensing locations, both of the sites visited used outdoor fueling. All the fueling station designs followed draft NFPA 57 recommendations. The following important conclusions were drawn:

- Weather protection should be provided for the dispensing equipment as long as ventilation and gas leak detection requirements of NFPA 52 and 57 are met.
- LNG fueling stations currently come in two types that utilize either pump transfer or pressure transfer of fuel. Both systems are described below.
- As required by draft NFPA 57, combustible gas alarms should be used to annunciate gas leaks and shut down the fueling operation.
- Fuelers should be aware of the small but hazardous combustible gas plume created during operation of a fueling nozzle.

Other analyses at the two sites are discussed below.

5.1 CENTRAL FUELING FACILITY EQUIPMENT

5.1.1 Description

Both sites reviewed in this study used rapid LNG transfer to fuel their buses. A typical LNG fueling station is shown in Figure 2-1. LNG fuel is delivered by tanker truck directly from an LNG receiving terminal or liquefication plant. The gas piping and on-site storage tanks should be confined (e.g., fenced-in) and protected from vehicles by a barrier. The LNG storage should be separated from the fueling station area and protected from vehicles by a barrier.

The LNG is moved from the stationary LNG tank by a cryogenic pump or a pressure transfer technique to the fueling dispenser. This dispenser physically resembles a gasoline pump at a local gas station. This dispenser measures and displays the quantity of LNG dispensed. The fueling nozzle should be of an appropriate design to provide the flow rate required to fill the buses in the time required. Also, the fueling nozzle may have a return line to vent "boiloff" away from the tank being fueled.

The fueling station should have a natural gas recovery system to capture the vented boiloff gas from the vehicle tanks. In some fueling techniques, a certain amount of natural gas must be vented from the top of the vehicle tanks to allow LNG to enter the tanks. This natural gas could be fed back to the natural gas distribution system or used in station operations.

5.1.2 Pump Transfer

The refueling system at one LNG site had a trailer-mounted, 3000-gallon cryogenic tank and a submerged cryogenic pump. The tank trailer was taken to the local gas distribution company to be filled, and was then parked at the transit site. The 3000-gallon size was selected to provide a two-week fuel supply for the demonstration vehicles. The dispenser had two mass motion meters, one of which measured pounds of liquid or gas supplied to the bus, and the other of which measured return vapor.

The cryogenic fueling pipe was vacuum-jacketed with insulated fittings. Three lines were attached to the tank trailer: LNG withdraw; LNG return; and vapor return. Two lines ran to the bus being fueled: LNG fill and vapor return. During fueling of the bus, the vehicle was first electrically grounded using a large diameter copper cable. The fueling was controlled by a programmable logic push-button control for automatic filling, but it could be operated manually if necessary. A connected printer provided a printout for each fueling showing time, date, bus number, and three weights of gas (in, out, and net).

The normal operating pressure of the LNG trailer tank was 40 psig. At a pressure of 100 psig the tank was vented through a tall stack. Rupture disks on the outer tank of the LNG trailer protected the shell from excessive pressure build-up in case of inner tank failure. All control valves in the cryogenic piping were ball valves and globe valves. All automatic shutoff valves were pneumatic operated (with nitrogen) and were equipped with spring return and fusible links. During the fueling operation LNG was directed to the nozzle or away from it by the programmable (computerized) controller. That is, if the controller sensed any type of blockage or bus tank full signal, it actuated a diverter valve to divert the LNG back to the trailer.

All segments of the piping that could be isolated by shutoff valves were protected by over--pressure relief valves. These relief valves discharged into the vapor return line. Sensors on the dispenser nozzle provided information on flow conditions to the electronic controller. A flow fuse on the nozzle prevented the entry of liquid into the vapor return line. The stainless steel metal braided dispensing hose was supported on a boom to facilitate the hose handling with relatively minimum effort by the fueler. The message center and fueling control panel were mounted inside an explosion-proof enclosure. The control system provided alphanumeric LED display messages and other information to the fueler.

The fueling station consisted of a canopy, kiosk, fire suppression system, gas detectors, and ultraviolet/infrared fire sensors. The UV/IR fire sensors were tied to an alarm and a dry chemical discharge, which could completely cover the area. The dry chemical discharge system also had two manual discharge buttons, one located remotely, to operate the fire suppression system. The dry chemical system held 2000 pounds of chemicals. All lights and connections were explosion-proof. The dispenser had an emergency stop button that stopped all operations and closed all valves. In addition, there were two emergency stop buttons on the tank trailer.

The fuel connection to the bus at this site was so low it required the fueler to crouch very near to the ground. Fueling and maintenance staff had to crawl halfway under the bus to reach the nitrogen connection used to purge the tanks. If the connection were brought out to the side of the bus, purging would have been simpler. This site had plans to recalibrate gas detector sensors on buses every six months.

5.1.3 Pressure Transfer

The vehicle fueling area at one LNG site included a large, vertically mounted tank with virtually all of the piping exposed between the tank (located in a pit) and the fueling dispenser. The dispenser was located at a distance in excess of 50 feet from the maintenance and office buildings on site. There was a canopy over the dispensing location and a concrete pad on which the vehicle was positioned for refueling. The backup for the main tank and a failed compressor was a dewar truck which also accepted off-loaded fuel. This system did not utilize a pump and, instead, delivered the fuel under pressure. No fuel metering system was installed at the time of the site visit. The tank held 13,000 gallons and approximately 1,000 gallons were used, per day. An LNG fuel delivery was made every 8 to 10 days.

The main cryogenic storage tank was 10 feet in diameter x 30-feet high. The tank operated at a nominal pressure of 40 psig and vented to the atmosphere at 110 psig. The tank sat on four "legs" inside an 8-foot deep concrete pit which was about 22 feet x 22 feet in cross section. The pit also contained two additional tanks, each with a capacity of 300 gallons, which acted as transfer tanks.

The vehicle filling operation was unique due to the absence of submerged cryogenic LNG pumps. Liquid transfer was effected by pressurizing the transfer tanks with compressed methane vapor stored in high pressure cylinders. The storage tank boiloff vapor was compressed and stored in ambient temperature CNG cylinders. There was no vehicle vapor recovery system.

The safety features of the fueling facility at this site were as follows:

1. All LNG storage equipment and principal liquid piping were located within the pit. This ensured that minor leaks of LNG remained in the pit. The pit itself had both combustible gas and oxygen sensors. There was also a methane sensor located directly adjacent to the point of fueling. These sensors, along with the sensors in the maintenance area, were tied into the control panel in the administration building.

2. The entire area of storage tank, compressors, and LNG storage cylinders was cordoned off by a chain link fence.

3. A Purple K fire extinguisher was located in a readily accessible place in the fueling facility.

4. The fueling nozzle was washed with a high-pressure nitrogen jet before being connected to the bus for refueling to remove any frost formation that might cause fuel leakage.

5. Before the bus was fueled, it was grounded with a heavy gauge copper wire (ending in an alligator clip).

6. Combustible gas sensors were provided in the fueling station.

7. A 200-gallon cryogenic tank was mounted on a pickup truck. This smaller LNG tank was used as a "nurse tank" to transfer LNG to a bus

stranded on the road or when the fueling system failed (e.g., due to compressor shutdown).

8. Four emergency stop buttons were located around the fueling area and the fueling equipment. These buttons killed power to the fueling area when activated. There were also two emergency stop buttons (set next to one another) located approximately 100 feet away on the exterior of the maintenance building. One killed power to the fueling area, and the other killed power to the maintenance area. There were no alarm signaling devices located at the fueling area. There were closed circuit television cameras located on site.

5.2 HAZARDS

Several hazards can be present at a fueling area. The draft NFPA 57 and other codes suggest several ways to mitigate these hazards. Some hazard mitigation methods are discussed below, including a combustible gas detection system, lightning protection, breakaway cages for fueling hoses, fueling area surveillance, classified electrical systems, telephone and kill switches at a safe distance from the fuel dispensing area, and static discharge mitigation.

A combustible gas detector system (including combustible gas and infrared detectors) recommended by draft NFPA 57 should be mounted in the fueling area and connected to an alarm system. If the dispensers are outside, they should be protected by a canopy of some kind and there should be both a ground-level and ceiling mounted combustible gas detection system. Most sites utilize a two-level alarm that annunciates visually and audibly the leak severity, disables equipment, and activates additional ventilation. This alarm should automatically turn off the dispensers and all electrical power to the fueling area at the higher alarm level (no more than 40 percent LFL), requiring manual restart. This alarm is also typically used to activate purge fans and notify station personnel that a gas leak or spill has been detected at the fueling facility. Such alarms should be tested and calibrated regularly to ensure proper operation.

Everything within an enclosed fueling area should be classified and explosion-proof, including incandescent light fixtures, conduits, and motors, within the area around the LNG storage and dispensing equipment (as suggested by draft NFPA 57). Several "kill" switches should be located near the fueling dispensers that completely shut down the fueling area. The details of this design are all suggested in NFPA 52 and 57. At least one kill switch and a telephone should be located nearby. However, this kill switch should be located at a safe distance from the fuel dispensing area to allow safe shutdown. This remote switch should not be in an area where the person pushing the switch would be at immediate risk. In addition to having a kill switch, the area should be under surveillance by security or the dispatcher (on a 24-hour a day basis or at least during normal fueling times).

For drive-away protection, the fueling hoses should be passed through breakaway cages downstream of a check valve. If the bus should pull away during the fueling process, the connection is intended to automatically disconnect and close the check valve, shutting off the LNG supply. Only a minimal amount of fuel should be able to escape. Most newer LNG vehicles have an ignition interlock system which will not allow the vehicle to start with the fuel door open. As specified by most states, the vehicle's engine should be off during fueling.

The fueling area and the fueling station itself should be adequately grounded and protected from lightning. The following procedures or equipment are suggested to enhance the safety of LNG fueling stations:

1. Methane sensors should be provided in all pits. If pockets of gas have accumulated in the pit following, for example, a minor leak of LNG, such sensors would reduce the risk of asphyxiation to an inspector performing either routine inspection or a maintenance operation.

2. The process diagram illustrating the location of different shutoff valves and piping should be visible from the fueling ramp, for example, on a chain link fence on the fueling ramp side.

3. An emergency shutoff valve should be located on the fueling ramp to cut off LNG to the hose. Because the supply of LNG is pressure- or pump-fed, a major leak can result if the hose or hose connection is severed during the fueling process.

4. An active fire suppression system (such as a dry chemical deluge system) protecting the fueling facility should be installed.

5. Fire or heat sensors or UV sensors should be installed in the fueling facility. Combustible gas sensors should also be installed in low areas of the fueling facility within 20 feet of the dispenser.

6. The fueling operation should be monitored routinely through visual aids such as CCTV. Also, there should be emergency phones or other communications equipment at the fueling facility.

7. Nurse tanks can be used as an auxiliary LNG storage to fuel the buses in case of compressor failure or to fuel a bus that runs out of fuel during its service. This tank should be maintained cold at all times.

   If such auxiliary tanks are kept at ambient temperatures, excessive liquid boiloff will occur during charging. The boiloff vapors have to be vented. This may result in a substantial vapor cloud near the fueling station, especially at ground level because the density of the vapor is greater than air. These boiloff vapors should be directed to a tall vent stack remote from the fueling island.

8. Every precaution should be taken to minimize or eliminate LNG leaks at the fueling valves and nozzles.

In conclusion, to reduce potential hazards, the following safeguards should be considered when designing an LNG dispensing station:

- Flexible fuel lines often have left-handed threads to connect to a fuel trailer. Left-handed threads should be indicated, so that if a person observes a leak and tries to tighten the connection, he or she will not make the leak worse and cause a bad spill or personal injury.

- Vertical-stack LNG vents should not be located where people may be underneath.

- Sites should provide more than one set of protective gear for fueling staff since assistance is often required with fueling. A second person should also have protective gear available. A locked compartment at the fueling station with a coded push button lock might better meet this requirement.

- Fire extinguisher ratings should be approved by the local fire authority. At a minimum the extinguisher ratings on the LNG fueling island should be equal to those for a gasoline fueling facility of comparable size and throughput.

- Emergency buttons should be located near the fueling station and also at a distance. The buttons should be clearly identified. A telephone should be located near the fueling island.

- An LNG fueling procedure should be posted and available inside the fueling island kiosk.

- The operation of the fire suppression system should be clear to the staff. The differences among various emergency signals (e.g., dry powder system alarm, building fire alarm, and gas detector alarm) should be taught and reinforced periodically.

- Combustible gas detectors should be clearly numbered. The monitoring panel should be accessible, with no bus parking allowed within 20 feet of the panel.

- The reset for the gas detector should be located to permit someone to reset the alarm safely in the event of a true alarm. The reset should also be located so that if a person were to collapse nearby from exposure to methane from a large fuel leak, he or she would be visible to other observers.

5.3 EMERGENCY EQUIPMENT AND PROCEDURES

Adequate emergency equipment and procedures should be available to personnel in the fueling areas including:

- The LNG storage and dispensing area should have emergency warning placards, with emergency telephone numbers listed, posted in several locations. A short list of emergency instructions should be posted near the fuel dispensers and kill switches.

- A telephone should be permanently mounted near the fueling station or within line-of-sight, with emergency contact numbers posted nearby.

- In an emergency, employees should be able to shut down the LNG dispensing system from a remote location. The emergency shutoff switch should be readily accessible to personnel, possibly near the telephone.

- Fueling operations should be observable from a remote location (e.g., from the maintenance manager's office) via remote TV cameras.

Detailed and specific written procedures and training materials should be available near the fueling hose to indicate how the fueler should operate the equipment, as well as procedures in the event of an emergency. Documentation should list the types of emergencies that could occur, how the fueler should diagnose each situation, what response the fueler should initiate, and where and when the fueler should turn for help. This documentation should be readily available to all personnel.

There may be incidents that will not allow the fueler (hostler) to reach the kill button. Also, panic and unfamiliarity can be a problem in an emergency. Therefore, very complete instructions associated with specific hypothetical incidents are essential to help the individual diagnose and respond to an emergency. Frequent periodic refresher training is also helpful.

5.4 FUELING ON THE ROAD VIA SERVICE VEHICLES

Because of the reduced range of many LNG transit buses, transit authorities have investigated methods of refueling an LNG bus on the street. To meet this need, one of the transit authorities purchased and upfitted a pickup truck as a "roadcall" truck to carry a "nurse tank." This truck was equipped with hoses and a fuel nozzle and could easily transfer fuel from its primary fuel tank to a disabled bus. This allowed the vehicle that was out of fuel to obtain LNG from the service truck and return to the fueling station under its own power. The program was working well at that transit authority.

6. MAINTENANCE

6.1 MAINTENANCE FACILITIES AND EQUIPMENT

At one site, one bay of the general bus maintenance facility was to service LNG fueled buses. These upgrades included moving all electrical outlets from floor level to six feet above ground, providing a heating system based on circulating hot water and installing methane detectors on the wall six feet above ground. In addition, all electrical equipment was made explosion-proof and the LNG maintenance bay was isolated from all other open maintenance bays by a ceiling-high cinder block wall.

The LNG maintenance area should be isolated from areas where ignition sources (such as welding operations, grinding, and machining) are present. This isolation will help prevent a major gas leak from reaching possible sources of ignition. Electrical panels located within LNG maintenance areas should be in a special enclosure equipped with a purged air system.

Both high-level and floor-level ventilation and exhaust systems should also be used to prevent gas from accumulating at either the high point of a sloped roof or in maintenance pits. Adequate ventilation with continuous backup may also provide advantages. Ventilation in maintenance pits and lift areas should be sufficient to ensure that a fuel system leak will not result in pockets of gas under the bus skirt of higher than the Lower Flammable Limit (LFL) concentration.

Electric motors used to actuate ventilators that are located close to the roof should be prevented from acting as ignition sources if they are opened to provide better ventilation in the event of a fuel release within the building.

Gas detection systems are considered by many to be a prudent safeguard in potentially hazardous areas (see additional discussion below) and provide one of the approaches that could be interpreted by "the authority having jurisdiction" as a way to declassify the area.

6.2 MAINTENANCE LEAK DETECTION

Maintenance facility design must also include systems for sensing LNG spills and natural gas leaks. Several designs for maintenance areas are being evaluated by transit agencies. These methods differ principally in the amount of equipment that is shut down during a sensor alarm. A second difference is the treatment of existing overhead ignition sources.

A common method used to sense natural gas leaks in a maintenance facility is to use a combustible gas detector system that provides only a warning in case of a major fuel leak. Usually, a number of gas detectors are used in maintenance areas. They are often centered over individual maintenance pits or centered in a maintenance bay, typically one to two feet below the ceiling.

In other facilities, a two-level alarm system was actuated by the detectors, depending on the concentration of combustible vapor detected. A low-level alarm was actuated at 20 percent of the LFL of methane in air. The alarm activated a red strobe, shut down all overhead and shop floor ignition sources (such as overhead heaters), turned on exhaust fans, and opened overhead doors (if they were closed). An audible and visual alarm was also sounded in the maintenance manager's office. A high-level alarm was actuated at 40 percent LFL. In addition to all annunciations associated with a low-level alarm, an alarm horn also sounded in the maintenance area.

At another LNG transit site, combustible gas sensors were installed in the maintenance building. These sensors, along with the sensors around the fueling area, were tied into a control panel that was located adjacent to the dispatcher's office in a separate administration building. The control panel was tied directly into an ADT alarm system that activated audible and visual alarm units when any sensor reached the warning level. The alarm system had two stages. The first, at 20 percent LFL, shut off pneumatic valves in the fueling system. The second, at 40 percent LFL, shut off the electricity to the maintenance building. The alarm system was also constantly monitored by a central station by way of a leased phone line. Upon alarm, the central station immediately alerted the local fire department which responded without separate confirmation. The separate dispatching office was equipped with both an alarm unit and an emergency stop button. Upon alarm the dispatcher was supposed to hit the stop button, killing power to the maintenance building.

At another site, audible and visual alarm systems were present within the maintenance building. These alarms were activated by the facility alarm system when methane was detected or when one of the associated manual pull stations was activated. There was also an emergency stop button adjacent to the pedestrian door exit that killed power to the maintenance building when depressed. There were no sprinkler, smoke detection, or heat detection systems located within the maintenance building. The methane detection system wiring was strung across the ceiling without using conduits.

In a preferred facility design, in addition to actuating alarms, sensors disable all shop floor power and overhead lighting. Ventilation is increased by starting exhaust fans or opening overhead doors that are external to the building or explosion-proof, and minor overhead and floor level ignition sources are shut off. In such facilities, there are no overhead gas heaters in the maintenance area; instead, the area is heated indirectly by hot water or forced air from gas heaters located elsewhere. All obvious overhead and nearby ignition sources are either omitted during facility construction or removed during refit of the facility.

The fundamental features of the preferred design make it more desirable over the long term. A transit agency that deploys such a system should also consider maintenance procedures related to equipment.

6.3 MAINTENANCE PROCEDURES

All personnel in the maintenance department should be familiar with the LNG bus maintenance procedures. Documentation on safe handling methods for LNG in the maintenance area should be readily available.

With a few exceptions, LNG buses brought indoors for service on the fuel system should have their fuel tanks purged. Written procedures or guidelines should be developed explaining when it is safe to bring an LNG bus into the shop and under what circumstances repair work can occur without purging fuel tanks. For example, one area of uncertainty is the policy that should be followed if open torch welding is to be performed on a non-fuel system item located close to the engine compartment or fuel tanks.

Another area of uncertainty is the procedure to be followed when repair work, expected to be quick or relatively simple (and performed with the vehicle fuel tanks full of LNG), turns out to be more lengthy or complex. For example, this may be true of some repairs to the brakes and suspension.

Maintenance personnel should be trained on the use of high pressure gas valves, pipe fittings, and Swagelok (compression) fittings. A Swagelok fitting consists of a body, two ferrules, and a nut that joins tubing to tubing or tubing to pipe thread. These fittings are unique to each other once they have been tightened. A used fitting that was originally tightened on one fitting body may leak if tightened against another fitting body. Fittings and body pairs should be numbered on disassembly so that they can be reassembled properly. This will not absolutely assure a leak-free system, but it has the best chance for success.

Written emergency notification and action procedures should be available to the maintenance crew. These procedures should be made known to personnel through concerted management policies.

6.4 HAZARDS

Vapors generated by any LNG release are cold and much denser than air. As such, methane concentrations will be high close to the ground. Combustible gas detectors should be located close to the floor, in case a spill occurs.

Ventilation should be provided in the pits or under the buses for dispersing potential gas leaks. Shop fans or table fans used to ventilate the undercarriage of a bus should conform to the NFPA code requirements for electrical equipment usage around combustible gases, as should all electrical equipment used in bus maintenance areas.

Annunciators, posters, and warning signs or lights in the maintenance shop should be in place to alert other personnel in the vicinity that an LNG bus is being serviced. Signs should remind workers to take precautions with flammable materials, ignition sources, and electrical equipment (for example, incandescent bulbs). Smoking should be prohibited in or near LNG buses. Signs should be posted throughout the maintenance area.

Reliable and accurate fuel level and fuel pressure gauges should be installed on the bus fuel tanks. These gauges, combined with appropriate procedures, will help ensure that a fuel tank is really empty before the bus is worked on. Breaking into a fuel system that is under pressure can pose significant risks to the maintenance crew.

7. VEHICLE STORAGE

At both LNG transit sites surveyed, all LNG vehicles were stored outdoors.

7.1 VEHICLE STORAGE FACILITIES

At many transit agencies, indoor storage is not an issue since all buses, including the LNG buses, are stored outside in designated areas of the agency. This is typical for transit agencies located in Southern states.

In the typical indoor bus storage area, increased ventilation for the LNG bus lane area is provided by roof-mounted fans and electrically operated doors at both ends of the storage building. Combustible gas detectors are suspended above each of the lanes about two feet below the garage ceiling. Each sensor is positioned over a lane and covers an area of about 625 square feet.

In the preferred facility design for indoor vehicle storage, strong overhead ignition sources (open flame heaters, switches, electric motors, and relays) are also removed. Combustible gas detectors are used to sense LNG fuel spillage or releases and, subsequently, deactivate any minor remaining ignition sources. Only indirect heating systems are used. A storage facility design that includes both an alarm system and removal of strong overhead ignition sources is recommended.

LNG detectors should typically trigger a three-level alarm system, depending on the concentration of methane detected. At 20 percent LFL, the doors at either end of the lanes are opened, exhaust fans and a red strobe light are turned on, and an audible and visual alarm is annunciated at the control panel in the maintenance manager's office. At 40 percent LFL, a loud horn is typically sounded and electrical service to minor ignition sources is interrupted.

If LNG transit buses are stored indoors, procedures and the facility's design must ensure that a release of the entire fuel load (due, e.g., to failure of a pressure relief device or a broken LNG line) would not jeopardize the safety of the facility or any of the transit employees. Removing open flame natural gas burner heaters and other strong overhead and floor level ignition sources is the safest way to design indoor storage facilities. The preferred facility design discussed above should be implemented according to recommendations outlined below in Sections 7.2 (Storage Facilities Equipment) and 7.3 (Storage Procedures).

7.2 STORAGE FACILITIES EQUIPMENT

LNG buses that are parked indoors should be parked only in storage lanes that have been initially designed or upgraded to accommodate them. Specific written guidelines or standard operating procedures should be available to instruct the dispatchers on the requirements for parking LNG buses in designated lanes only. In many instances, parking areas that are suitable for diesel buses would be unsuitable for LNG buses.

Any overhead garage door operating motors, exhaust fan motors, and switches or relays either should be moved from the ceiling space (typically outside on the roof) or made explosion-proof. Open flame heaters should be removed from service, and only indirect heating systems should be allowed in the vehicle storage area.

Gas detection and alarm systems should allow the person monitoring the system to easily associate an alarm signal at the control panel with a location at the storage facility. A map of where each sensor is located in the facility should be placed on the outside of the control panel.

In most facilities, particularly in the North where freezing temperatures regularly occur, the entire storage area is sprinkled utilizing both wet and dry systems. Dry systems are often located in the vicinity of exterior doors, while the rest of the facility is protected by a wet system.

Combustible gas sensors should be installed as close to the ceiling as possible. The location should keep to a minimum the volume of space near the ceiling where methane can accumulate without being detected by sensors.

7.3 STORAGE PROCEDURES

Written standard operating procedures should be available to dispatchers, showing them how to handle different types of emergencies that could arise in the bus storage area.

Also, dispatchers must track the length of time that has elapsed since each LNG bus was operated and compare this time to the expected time of venting. An alternative procedure would call for regular reading of the pressure gauge on each parked bus. Such reading should be taken at least daily and probably every shift.

Also, emergency pull stations should be available in work areas so that if there is an LNG spill or a natural gas release in the shop, any employee can signal the alarm and turn on the ventilation system without delay or waiting for sensor activation.

8. LNG BUSES

Both heavy-duty and light-duty LNG buses were observed in revenue service. As this section explains, they were configured quite differently in engine size and fuel system demands.

8.1 FUEL TANKS

8.1.2 Heavy-Duty Coaches

The 40-foot buses used in LNG service at one transit site had vacuum-insulated fuel systems, consisting of three manifolded cryogenic tanks. Liquid was removed by a hydraulic positive displacement pump and pushed to a coolant/fuel heat exchanger to be boiled. The gas then passed through a second air/fuel heat exchanger before going to the regulators at approximately 300 psi. Then it was mixed with intake air a few inches above boost pressure and drawn into the cylinders. Each bus had several combustible gas sensors that were active when the master switch was on.

Each LNG bus had three cryogenic tanks with a total water volume of 220 gallons. They could be filled with approximately 180 gallons of LNG.

8.1.3 Medium-Duty Coaches

The 30-foot coaches at one transit site carried two LNG tanks, each having a capacity of 180 gallons. These tanks were mounted under the chassis with their axes parallel to the road. Each bus was provided with two gas detectors, one under carriage close to the LNG tanks and the other in the passenger compartment behind the driver. A gas detector monitor panel was also provided in the driver compartment.

The safety features in both bus sizes included:

- Electrically operated natural gas solenoid valves to effect, in case of need, immediate shutoff of fuel supply to the engine.

- Engine cutoff switch which was activated when the fueling compartment door was ajar.

- Two LNG tank pressure relief valves, one of which opened at 235 psig and the other at 350 psig.

8.2 FUEL TANK STORAGE PRESSURE

The engine fuel pressure requirements for the two classes of LNG vehicles dictated significantly different fuel tank and delivery systems. The heavy-duty transit buses utilized a turbocharger, spark ignition engine that had a fuel pressure requirement in excess of 100 psi. This high fuel pressure dictated the use of a cryogenic pump submerged within the fuel tank to supply the relatively high fuel pressures. The actual tank pressure, however, was nominally 45 to 60 psi, but it could rise to 90 psi before resetting relief valves were actuated.

A pumpless system was utilized on the medium-duty 30-foot buses. This gasoline derivative engine was not turbocharged and fuel pressures as low as 50 psi would provide proper fuel control for the engine. Actual fuel tank pressures were similar to those of the heavy-duty vehicle, but a vehicle cryogenic pump was not needed to supply this engine.

8.3 SAFETY FEATURES

Buses at one site had methane detectors, alarms, ultraviolet/infrared fire detectors, and a dry chemical fire suppression system. These systems protected the engine area and fuel tank area. The methane sensors on the bus were active only when the bus was switched on. On the one hand, this strategy meant there would be no continual alarms from leaks at fuel nozzle. On the other, there would be no assurance that the bus would be safe when it was started up after fueling.

These buses had permission to go through tunnels. The local natural gas distribution company aided in gaining this permission. With regards to range, they took one bus on a 60-mile round trip to another city. One representative of the transit company noted that a false release of dry chemical agent into a bus on the street could cause panic for passengers, motorists, or passersby in the vicinity.

9. TRANSIT BUS OPERATIONS

9.1 PUBLIC ACCEPTANCE

An important aspect of bus operations is to assure public acceptance of the transit authority's programs and practices. To assure that the authority's plans are presented correctly to the public, transit management must provide a continuing education and training program to the bus operator. The bus operator will serve as the main conduit of information to the public on the benefits and safety measures employed in the use of LNG fuel.

LNG buses, in general, have performed well and have achieved both driver and public acceptance. However, bus operators at one site reportedly thought that LNG buses were slow.

9.2 DRIVER TRAINING NEEDS

Current practice is to schedule periodic training sessions for bus operators to review correct procedures for LNG buses. These LNG procedures are usually contained in a handout that addresses such issues as bus accidents with and without leakage of LNG and the response to a fire on a LNG bus. Although more detailed training for LNG bus operators is needed to achieve both awareness of the fuel and a public acceptance of LNG as a safe and needed diesel replacement, current efforts are achieving meaningful results.

Bus operators should know correct emergency procedures and be tested accordingly. Detailed instruction should be available to the bus operator while on the bus and cover what to do in all on-board emergencies.

Additional training would provide LNG bus operators a working knowledge of the buses' LNG systems. This knowledge would assist in correctly answering questions that could be asked by passengers. For harmonious relations and public acceptance of LNG, it is essential to correctly answer any questions and concerns that may be voiced by interested passengers. Often these questions can be anticipated and a meaningful reply formulated by the transit staff and management.

10. OCCUPATIONAL HYGIENE ISSUES

One focus of this study was to address possible implications for transit worker safety and hygiene in the work place if LNG were the principal engine fuel for transit operations. Since little has been published on the subject to date, one of the program objectives was to increase the amount of data available to the transit community on the levels of natural gas in the work environment and its effects on staff safety.

10.1 OBJECTIVE

The objective of the natural gas concentration measurements was to determine if natural gas levels associated with the fueling, maintenance, storage, and operation of compressed natural gas buses posed a fire hazard, a health hazard, or represented a significant release of fuel into the environment. Natural gas concentrations were measured at both sites.

10.2 METHOD

The natural gas concentration measurements were made using a MIRAN 1B portable gas analyzer. The analyzer contains a calibrated infrared spectrometer as well as a sample handling pump. The MIRAN is capable of measuring methane concentrations from 2 to 5000 ppm by volume over several ranges. The calibration of the methane scales on the MIRAN was verified using a cylinder of certified standard calibration gas (containing both methane and ethane in air) prepared by Matheson.

10.3 APPLICABLE STANDARDS

The apparent Threshold Limit Value (TLV) for natural gas is 10,000 to 15,000 ppm depending on the quantity of higher hydrocarbons in the gas. The LFL for natural gas is about 5 percent or 50,000 ppm. Below this limit, mixtures of air and gas are too lean to burn and will not ignite. There is also a higher flammability limit of 15 percent. Above this limit the mixture is too rich to burn.

10.4 RESULTS

Results of the methane gas concentration measurements from one site are shown in Table 2-1 below. In examining the data in this table, the following points should be considered:

- All concentrations are given as ppm by volume of methane or as percent LFL. For reference, a concentration of 1 percent by volume equals 10,000 ppm. The LFL of natural gas is 5 percent or 50,000 ppm. Therefore, each percent LFL is equivalent to 500 ppm of methane.

- Because of natural winds and air currents, readings often fluctuated. In such cases, approximate values or ranges are given.

Table 2-1. Natural Gas Concentration Measurements for Typical Transit Agency Locations

Ref No.	Situation and Location	Methane Concent., ppm or % LFL
Fueling Station I		
1	General background at fueling island prior to any fueling activity.	28-30 ppm
2	Fueling bus A: Between fuel storage and fueling island.	580 ppm
3	Fueling bus A: About 1 meter upwind from fueling connection during fueling.	3% LFL
4	Fueling bus A: Near concrete under fueling nozzle after partial fueling was completed. A small puddle (about 100 mm diameter) of LNG from a connection leak had evaporated and no liquid was visible.	38% LFL
5	Fueling bus A: During remainder of fueling. Small leak from fuel nozzle. About 1 meter high and about 2 meters from fueling connection.	3% LFL
6	Maximum reading during walk around the perimeter of the fuel storage area immediately after fueling.	1500 ppm
8	General background at fueling island during fueling.	300-400 ppm

Table 2-1. Natural Gas Concentration Measurements for Typical Transit Agency Locations (Continued)

Ref No.	Situation and Location	Methane Concent., ppm or % LFL
Fueling Station I		
9	Standing near rear of LNG storage area during fueling.	700-900 ppm
10	Inside rear compartment of LNG storage area during fueling. Note there was a small fitting leak at this time.	40% LFL
11	Fueling bus B: At side of bus, about 2 meters away from fuel nozzle during venting to reduce tank pressure.	5% LFL
12	Fueling bus B: At entrance to fueling connection compartment on bus compartment during fueling. Compartment door fully open. Fueling nozzle dripping fuel onto concrete pad.	40-50% LFL
13	Fueling bus B: About 1/2 meter high, 1 meter downwind from fueling connection.	10% LFL
14	Fueling bus B: Above fueling nozzle while fueling. Measurement made about 1 meter above ground.	8-9% LFL
15	Fueling bus B: About 1/3 meter above fueling nozzle during fueling.	53% LFL
16	Fueling bus B: After fueling was completed and bus being driven away. Along side bus about 2 meters above ground.	2% LFL
Fueling Station II		
1	SW corner of fueling station.	170 ppm
2	Near bus C exhaust.	280 ppm
3	Approximately 1.5 meters from bus C fueling connector during fueling.	833 ppm
4	Approximately 0.5 m above bus D fueling connection during fueling.	18-20% LFL

Table 2-1. Natural Gas Concentration Measurements for Typical Transit Agency Locations (Continued)

Ref No.	Situation and Location	Methane Concent., ppm or % LFL
Fueling Station I		
5	Near rear vent of bus E after fueling. Vehicle tank was reportedly slightly over-filled.	100% LFL
6	Beneath nozzle during fueling of bus F. Probe was approximately 0.3 meters off ground.	13% LFL

In examining the above data, the following points should be considered:

- All concentrations are given as ppm by volume of methane. For reference, a concentration of 1 percent by volume equals 10,000 ppm. The LFL of natural gas is 5 percent or 50,000 ppm.
- The concentrations given are for methane. However, because the LNG is essentially all methane, the data may be taken to refer to natural gas as well.
- Because of natural winds and air currents, readings often fluctuate. In such cases, approximate values or ranges are given.
- A general survey of the area near where LNG buses were parked did not show any notable natural gas concentrations.

10.5 OVERALL ASSESSMENT OF NATURAL GAS CONCENTRATIONS

No general background methane concentration values were measured in the work place which even approached either the TLV or the LFL. These measured methane concentration data indicated that in the absence of major leaks or abnormal conditions, the natural gas concentrations in the general fueling area associated with the use of LNG buses were relatively low.

However, the data also indicated that localized methane concentrations were present which, at some distance from the source, approached the LFL and undoubtedly exceeded the LFL closer to the source. These local concentrations were a cause for concern inasmuch as they could be ignited by static electricity of other ignition sources and cause a flash fire. The concentrations near the fueling nozzle were of special concern because during the time the connection was made and broken the fueler's face was located close to or even within a flammable zone as the fitting was vented.

11. EMERGENCY PLANNING

As part of an overall facility system safety plan, a transit agency that is operating with alternative fuels should consider aspects of an emergency plan. The plan must be site-specific and relate to physical characteristics and capabilities of the responding agencies (fire, EMS, and police). Other issues to be addressed include response time, capability of staff to address the emergency, and other issues that are discussed below.

11.1 PLANNING, ESTABLISHING, AND DOCUMENTING EMERGENCY PROCEDURES

Easily accessible written documents should be provided to dispatchers to initiate emergency response procedures for gas releases that are detected inside the bus storage area. Written documents on emergency response procedures should also be in place for the fueling facility, maintenance shop, and bus storage area. For example, these lists of "do's and don'ts" should indicate who is responsible, when to take action, and who to notify.

The gas detection system annunciators in the maintenance manager's office or some other staffed area should indicate graphically the location of fuel releases, and individual sensing units should either be labeled with the same legend as in the annunciator panel or show through a warning light that they have been activated.

A procedure for recording safety incidents, accidents, or alarms from the gas detection system should be enforced. A written record should be kept for tracking fuel leak incidents and similar events.

11.2 COORDINATION WITH LOCAL EMERGENCY MANAGEMENT AGENCIES

One LNG site seems to have had a very close working relationship with the local fire department. All of the LNG related alarms sounded at the facility as well as at the nearest fire station. The agreement with the local fire department called for the initiation of a response no matter the cause or size of the incident, once the alarm sounded.

The management at this site indicated that the emergency response personnel in the fire department had been briefed on the safety issues of the LNG, including the behavior of LNG vapors and the precautions that could minimize danger.

Specific written agreements, formal understandings, or a coordination protocol should be developed between the transit authority and the local emergency officials. The terms of authority, in an emergency, between the transit operator and local/municipal emergency response agencies should be made clear.

Local fire department personnel should be familiar with the LNG bus layout and storage and maintenance facilities. Officials from every local community through which LNG buses operate should also be included in emergency response planning.

11.3 STAFF DRILLS AND TRAINING IN EMERGENCY PREPAREDNESS

Tabletop exercises, but preferably emergency drills, should be conducted with the fire department or police department to educate these emergency response agencies on the details of the LNG bus and safe handling procedures.

In a large metropolitan area, a number of different political jurisdictions may provide their own emergency services. All emergency management personnel in these areas should be familiar with the equipment and operation of LNG buses and be provided with remedial training by the transit agency.

One specific area of concern is bus engine fires. Transit staff should be trained and prepared for a fire involving an LNG bus.

12. MANAGEMENT AND SAFETY AWARENESS

12.1 MANAGEMENT COMMITMENT TO SAFETY AWARENESS

Transit management should be conscious of LNG safety requirements and committed to improving procedures and guidelines that will ensure safe operations.

Management also should encourage employees to learn about all aspects of LNG bus operations. Also, a direct and formal involvement by senior management promotes worker safety. Operations should be based on written procedures, not merely "word of mouth." Corporate policy should foster gathering, formalizing, and disseminating LNG safety knowledge, including the relevant procedures for accident prevention. A formal hazard analysis for LNG vehicles and facilities should be completed for every transit site.

12.2 THE EXPERT SOURCE

12.2.1 Responsibilities

One individual in the transit organization should be specifically charged with improving safety in LNG operations. This person should be aware of LNG safety issues and corresponding worker training, system enhancement, and technical product improvement issues, and should proactively work to improve safety.

All LNG activities should be coordinated among different departments within a transit agency. Because of the novelty of alternative fuels, it is common that a champion of the technology will reside within the maintenance operation. If so, special provision must be made for the transfer of this knowledge to the drivers and fuelers. Responsibilities of each department should be clear, as should appropriate delegations of authority.

12.2.2 Communications

Material provided to staff should be adequate to ensure safety compliance in all operations. Documents should be available at work locations (in the fueling area, maintenance bays, storage area, or on-board an operating bus) for quick reference to execute emergency procedures. Tests or other methods should be in place to determine if the personnel trained understand the features and issues associated with maintaining and operating an LNG bus or the facility. Formal feedback mechanisms should be available for an operator or a shop worker to provide responses, based on his or her experience in the field, to either modify the training content or enhance it.

A program for exchange of safety information with other local transit administrations using the same fuel should be established and maintained.

13. TRAINING

Training of key employees who must interact with the new LNG fuel is essential in assuring the overall safety and operation of the facility. All transit agencies have employee training programs available for their staff. This training effort must be extended to include any changes that are made in the normal operations by the use of LNG bus fuel. When possible, the fuel supplier should provide training and technical assistance in LNG handling. A formal training program should provide instruction to the following groups:

- Fuelers (hostlers);
- Drivers;
- Mechanics; and
- Public Safety agencies.

One transit site planned to provide its employees with a 3-hour classroom lecture based training program. The topics in the lecture covered LNG properties and LNG system components in a bus, including the fire protection system, fueling facility details, maintenance facility, and safety procedures. The bus fire suppression system vendor also held a one-time-only class describing the fire protection system on board the LNG bus. In general, all personnel who worked on any part of the LNG system had to undergo some sort of "familiarization" training, as detailed below. This site was also in the process of composing a video film library so that any person interested in the LNG bus could borrow and view the training film at his or her own convenience. It was not clear whether paid staff time would be allotted for this activity.

13.1 TRAINING PRINCIPLES

Training materials used to instruct transit employees for alternative fuel use should adhere to the following principles:

- Easily accessible written procedures should be provided at key locations throughout the LNG facility. These procedures should be available for any staff with responsibility for the operation of LNG buses.

- Employees should, above all, be provided with the information needed to perform their jobs. Thus, training materials should only secondarily be aimed at marketing alternative fuels.

- The content should be technically accurate and understandable by the intended audience.

- The "why" as well as "how to," as far as possible, should be explained.

- Information on both routine activities and emergency procedures should be provided. Emergency procedures should be arranged in a simple form and placed in an easily accessible location.

- Testing or certification should be provided to ascertain the level of knowledge actually attained.

- A formal mechanism for updating and transferring new information and experiences to the existing staff should be instituted.

- Periodic retraining or review should be established.

- Training materials should be specific to the transit site. For example, there should be a general description of the facility, a map of the location of various sensors, emergency cut off switches, emergency communications equipment, etc. The manuals should be easy to use, especially in an emergency.

In addition, these three tactics would enhance the personnel training at LNG transit sites:

1. A formal training program should be conducted at the company for the personnel working with LNG related systems.

2. An emergency response plan document should be available.

3. Written procedures to follow in a normal business day and under accident conditions should be developed and made available to all staff. The accident procedure should be specific to LNG. For example, it should

explain the method for determining the existence of a LNG leak and the appropriate response.

There should be written guidelines or training manuals for all personnel categories (dispatcher, fueler, LNG vehicle maintenance mechanic, etc.).

13.2 FUELER INSTRUCTION

The fuelers at one site received both classroom and hands-on training in fueling a bus, emergency switch operation, and response to emergencies.

Fuelers (or hostlers) should be required to meet an LNG certification as part of their training. The test should demonstrate that trainees understand the various aspects of the fueling process and safety issues and, more importantly, the order of procedures in the event of a natural gas release.

Such training would include both classroom and hands-on training. The latter would involve the normal fueling operations and the emergency shut-down procedures. During the classroom training, video films on safety and normal fueling procedures would be shown and discussed in a later wrap-up session. A one-page handout on LNG bus fueling given to the students would provide a reminder for later use.

The curriculum for formal training of staff conducted by one transit authority covered the following subjects:

- Fuel Storage and Dispensing Station Familiarization;
- Fueling Station Preventive Maintenance;
- Fuel Nozzle Training (Fueling Station);
- Coach Orientation;
- Coach Emergency Training; and
- LNG Orientation for Municipal Emergency Response Personnel.

All curriculum items should focus on LNG-specific issues.

13.3 DRIVER INSTRUCTION

The bus operators at one site received a half-hour training lecture, however, no special training was provided for driving a LNG bus. Bus operators should also be tested and certified in both the basics of operating an LNG bus and in responses required of them in an emergency. A system should be developed for tracking the training program. Managers should be able to see if all staff have been to all training classes or understand all aspects of the LNG training provided.

A typical driver training session would familiarize the trainee with the LNG coach features, its operability on a road, its turning radius, etc. The course would include topics on alternative fuels, the construction features of LNG coaches, fuel cylinders, and any changes in the road maneuverability of the vehicle.

As part of this course, drivers would also be trained to read the fuel gauge light on the dashboard panel, initiate minimal emergency response procedures (such as operating the fuel shutoff valve), and follow the procedure for contacting the dispatcher to indicate LNG-related problems. In addition, the bus operator would be shown an LNG safety film including the types of accidents that might lead to fires and explosions.

Written instructions for operator actions should be posted in the bus in case of emergencies involving an LNG release. Detailed training should be provided to the bus operators in the following areas:

- LNG familiarization for transit personnel;
- LNG coach orientation;
- Coach emergency training for LNG; and
- LNG orientation for municipal emergency response personnel.

13.4 MECHANICS INSTRUCTION

The maintenance personnel at one site had little or no hands on training on LNG buses because few buses were in operation and also because the engine and the LNG fuel systems on the buses were still under warranty. However, the maintenance personnel were "exposed" to a 3-hour classroom lecture. The maintenance training was being developed with emphasis on problem diagnosis. A program of certification and periodic recertification for mechanics allowed only fully trained personnel to repair LNG buses.

A program with "hands-on training" with LNG buses would be most valuable. Specific emphasis of this training would be to educate the staff on the following:

- LNG bus orientation;
- LNG familiarization for transit personnel;
- LNG orientation for municipal emergency response personnel;
- Overall LNG system and components in a bus;
- Safe procedures with cryogenic liquid fuels;
- Leak detection for LNG, assuring that vehicles are regularly inspected with portable gas detectors;
- LNG engine familiarization and proper engine tuning;
- Ignition system and engine controls;
- Carburetion system;
- Coach air conditioning and heating systems; and
- Swagelok safety seminar (fuel supply lines).

Specific points that should be covered by the training include:

- Response to a fuel system leak, especially the locations of shutoff valves.

- The need for and the procedures for fuel system inspections for leaks and damage from road debris. These inspections should include, but not be limited to, the LNG fuel tanks.

13.5 PUBLIC SAFETY INSTRUCTION

The training department personnel or designates should develop a "road show" with an LNG bus and take it to various fire departments in the local metropolitan area and demonstrate its features to fire department personnel. The purpose of this "road show" would be to educate the fire departments on the components of the LNG bus, including the locations of emergency shutoff valves, battery disconnects, fuel line features, details of pressure, and make of fuel tanks. The transit operator's training department should provide each fire department visited with copies of printed documentation.

From this type of exposure, the fire department would become aware of the correct response to an LNG bus emergency. The fire department should be invited to bring fireman trainees to the LNG facility. Transit personnel should show the trainees the fueling station, its operations, and LNG bus details (such as shutoff valves on each LNG tank, the fuel system shutoff valve, the battery cut-out switch, etc.). This training could be supplemented with videotapes from the Compressed Gas Association on safe handling of cryogenic liquids.

One transit site maintained a good library of information on LNG including: LNG physical and thermodynamic properties, safety guidelines developed by the LNG industry, and first aid response. Also, a few videotapes on related subjects were available.

14. CONCLUSIONS

14.1 SUMMARY OF RECOMMENDATIONS FOR SUCCESSFUL LNG OPERATIONS

Based on the two industrial surveys, the following recommendations are of the greatest significance in planning and safely operating LNG transit systems:

- Training of operating staff. One of the most important resources in providing safe working conditions is the provision for a clear understanding by operating staff of the agencies of LNG fuel and the proper procedures to follow when using or maintaining LNG vehicles and equipment. Both safety and operational information should be available in a form transit employees readily understand and at appropriate locations in the work place. Formal training updates should be given periodically and an institutional mechanism established for experienced personnel to share their LNG fuel experiences with less experienced staff.

- Control of strong ignition sources. Strong ignition sources should be removed from areas where LNG buses are stored, maintained, or fueled. Of primary concern are strong overhead and floor level ignition sources such as open-flame gas heaters, motor starters on fans and door openers, and other spark-producing electrical equipment (electric bug zappers, etc.).

- Alarms and other warning systems. Warning systems consisting of combustible gas sensors and an alarm system should be installed in all LNG facilities. These systems can warn of potential hazards even when personnel cannot detect a fuel buildup or when personnel are not present. These warning systems can be configured to independently increase ventilation rates to more quickly remove any gas buildup and to disable potential ignition sources. Maintenance and testing programs for such alarm systems should be in place and implemented.

- Facility ventilation. Preventing gas buildups in LNG facilities is one of the primary methods of reducing potential fire hazards. Facility ventilation requirements for LNG vehicles differ significantly from diesel- or gasoline-fueled vehicles. Ventilating ceilings and high areas is especially important and must be done in conjunction with low level ventilation because the fuel vapor can also be heavier than air.

14.2 REMAINING ISSUES AND TOPICS

Several relevant questions outside the scope of this study have yet to be resolved, particularly the complex issue of code coverage and interpretation, appropriate building and equipment standards, and the best methods for training and certifying transit employees in the use of LNG as a transit fuel. In addition, the following issues must be resolved:

- More information is needed on the successful deployment and use of combustible gas detectors within transit facilities, including the number and location of detectors and periodic calibration requirements. Moreover, detector response time must be consistent with the time required to implement remedial actions.

- Strategies for handling tank venting need to be developed and implemented.

- Formaldehyde buildup in bus storage facilities during morning pull-out should be monitored as the LNG fleet size increases within a given facility.

- A system safety and hazard assessment analysis needs to be performed to more clearly identify the safety implications related to the choice of fuel tank location on the bus. This safety assessment should include the piping and valve associated with the fuel tanks.

☆U.S. GOVERNMENT PRINTING OFFICE: 1996 - 701-094/40000