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U.S. Department of Transportation
Federal Transit Administration

Clean Air Program

Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel

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

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Final Report

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13. ABSTRACT (Maximum 200 words)

The use of alternative fuels to power transit buses is steadily increasing. Several fuels, including Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG), and Methanol/Ethanol, are already being used. At present, there are no comprehensive facilities guidelines to assist transit agencies contemplating converting from diesel to alternate fuels. This document addresses that need.

This guidelines document presents various facility and bus design issues that need to be considered to ensure safe operations when using LNG as the alternative fuel. Fueling facility, garaging facility, maintenance facility requirements and safety practices are indicated. Fuel properties, potential hazards, fuel requirements for specified level of service, applicable codes and standards, ventilation, and electrical classification, among other items, are also discussed. Critical fuel related safety issues in the design of the related systems on the bus are also indicated.

A system safety assessment and hazard resolution process is also presented. This approach may be used to select design strategies which are economical, yet ensure a specified level of safety.

This report forms part of a series of monographs being published by the U.S. DOT/FTA on the safe use of alternative fuels. Documents similar to this one in content have been published for CNG, LPG, and Methanol/Ethanol.

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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 (he) = 4,000 square meters (m^2)

MASS-WEIGHT (Approximate)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilograms (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
(x + 460) / 1.8 = y °K

PRESSURE (Exact)

1 psi = 6.8948 k Pa

ENERGY & ENERGY DENSITY (Exact)

1 Btu = 1.05506 kJ
1 Btu/lb = 2.326 kJ/kg

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 (he) = 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) = 13 cubic yards (cu yd, yd^3)

TEMPERATURE (Exact)

[(9 / 5) y + 32] °C = x °F
(y x 1.8 – 460) = x °F

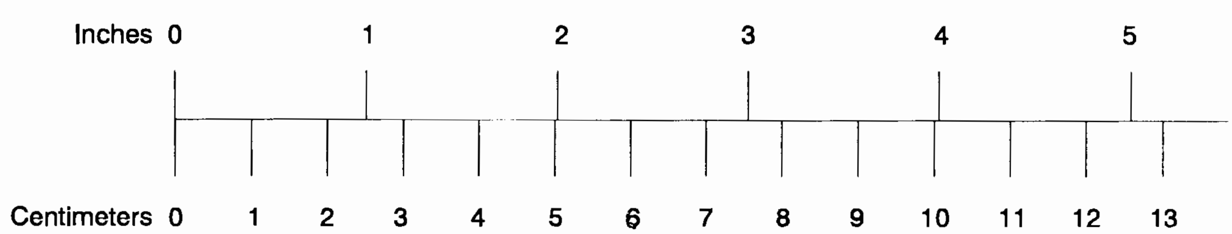
PRESSURE (Exact)

1 M Pa = 145.04 psi

ENERGY & ENERGY DENSITY (Exact)

1 MJ = 947.81 Btu
1 MJ/kg = 430 Btu/lb

QUICK INCH-CENTIMETER LENGTH CONVERSION



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°

Listing of Tables

Listing of Figures

Chapter 1
Introduction

At present over 1000 transit buses using alternative fuels (fuels other than diesel or gasoline) are in revenue service in the United States; their number continues to increase as additional transit systems begin to use alternative fuel buses. Safety is one of the key issues in the use of alternative fuels both in operation and servicing of the buses. However, at present, there are no comprehensive guidelines for the safe design and operation of alternative fuel facilities and vehicles for transit systems to follow in either retrofit or new facility designs. The Federal Transit Administration (FTA) has therefore initiated the development of "Design Guidelines for Transit Bus Facilities Using Alternative Fuels."

This report provides design guidelines for the safe use of ***Liquefied Natural Gas*** (***LNG***). It forms a part of the series of individual monographs being published by the FTA providing guidelines for the safe use of ***Liquefied Natural Gas*** (***LNG***), ***Compressed Natural Gas*** (***CNG***), ***Liquefied Petroleum Gas (LPG)*** and ***alcohol fuels (Methanol and Ethanol)***. Each report in this series describes, for the subject fuel, the important fuel properties, guidelines for the design and operation of bus fueling, storage and maintenance facilities, issues on personnel training and emergency preparedness.

1.1 BACKGROUND

The Clean Air Act Amendments of 1990 mandate the reduction in tailpipe emissions of air pollutants from mobile sources including heavy duty vehicles or engines. In addition, the National Energy Policy Act of 1992 sets a national goal to replace the use of up to 30% of the petroleum fuel with alterative fuels by the year 2010 and mandates the use of alternative fuels in the nation's Federal, state, and fuel provider fleets at a rate not less than the promulgated phase in rate. In addition, several states have promulgated statues encouraging or requiring the use of alternative fueled vehicles by fleet operators.

The increasing use of alternative fuels in the nation's transit bus fleet is a consequence of the above statutes. Their use has also been encouraged by the FTA's Alternative Fuels Initiative (AFI) begun in 1988 and by a number of demonstration programs funded by the FTA. The AFI involved the field testing, demonstration and assistance in revenue service placement of buses powered by ***LNG***, ***CNG***, ***LPG***, ***alcohol fuels***, and hydrogen fuel cells.

Each of these alternative fuels has unique physical and chemical properties which differ from those of traditional diesel fuels in common use in transit bus fleets operating in the U.S. Transit agencies have decades of knowledge and experience on the use, handling and storage of diesel fuels. However, the use of these alternative fuels in buses is relatively new. The unique properties of the fuels affect usage, storage, handling and response to emergencies.

A number of transit agencies are already operating fleets of alternative fueled buses. However, the transition has been made somewhat difficult because of the absence of adequate guidelines to address the issues involved in the design of facilities and vehicles to ensure a safe and smooth transition and operation. The industry as a whole is learning from the experience of some of the pioneers in the transit industry who have successfully converted to operating alternative fuel buses. There is, however, an urgent need to provide guidance to other transit systems that are either contemplating transitions or are initiating the process in the near future. This document is intended to provide some guidance to these transit agencies in their efforts to make the transition to alternative fuel safe and efficient.

1.2 PURPOSE AND SCOPE

The purpose of this document is to provide guidance, information on safe industry practices, applicable national codes and standards, and reference data where available which the transit agencies need to review when considering modifications to their existing facilities or when planning new bus facilities to safely use ***LNG*** as an alternate fuel.[(1)]

The scope of this document is limited, generally, to discussing issues related to bus facilities, e.g., bus fueling, storage and maintenance facilities. The overall safety of an alternative fuel bus facility depends not only on the safety systems designed into the fixed facilities, but also on (safety) systems provided on the buses and on the knowledge and training of the facility's personnel. Therefore, this document also includes design issues related to vehicle safety and personnel training issues.

In Chapter 2, issues and practices related to the use of the specific alternative fuel considered in this document are presented. The topics covered include:

- Fuel properties relevant to safe operations;

[(1)]A series of documents similar to this in scope and content have been published by the U.S. DOT/FTA on other alternative fuels, namely, ***LPG, CNG, Methanol/Ethanol.*** See the section on References for detailed citations.

- Design issues related to the
  - Fueling facility
  - Bus storage/parking facility
  - Bus repair facility
  - Bus fuel system and safety features
- Personnel training and operational procedures; and
- Emergency preparedness and other special issues.

Chapter 3 discusses the framework for performing a ***system safety*** analysis using the Military (MIL) Standard 882C, "***System Safety*** Program Requirements" as the basis. The ***system safety*** process is applicable when guidance on a specific design approach is not available or when a unique design issue warrants the use of detailed ***hazard*** analysis. The ***hazard*** resolution process requires giving full consideration to all elements of the alternative fuels system, including the vehicle. In addition, this assessment procedure may be beneficial when a transit authority initially begins operation with a small number of alternative fueled vehicles.

For specific guidance, readers are encouraged to use this document and several related publications identified in the Reference Section of this document.

This document is intended to be a reference guideline document on facility design issues and **SHOULD NOT** be considered as a specification manual or a substitute for existing local, state or national codes and regulations. In addition, the reader should consider the following issues when reading this document.

- Every facility that is either being modified or constructed anew should be in compliance with all local, state and national codes and regulations.

- The information provided in this guidebook is by no means exhaustive on the subject of facility design or personnel training or any other associated issues. The transit system should consult with knowledgeable engineers, consultants, fuel supplier, design Architectural & Engineering (A&E) firm(s) and the staff of the local authority having jurisdiction to design the facility consistent with local codes, regulations, and conditions.

- This document references sections of national codes or regulations. Such references to particular sections of the standards or the regulations are NOT intended to convey the impression that only those sections apply. They are, however, intended to get the reader started or directed to the appropriate sections in the standards or codes. It is recommended that all provisions of a currently adopted code or standard be reviewed thoroughly.

1.3 EXPLANATORY INFORMATION

Several types of information are presented in special ways, in this document, to make the information "friendlier" to the reader. These methods include several lists at the end of the document. The types of information presented are:

Technical Terms	Terms that have a special meaning relative to the subject matter in this report are ***highlighted (i.e., bolded and italicized)*** where they appear in the text. All terms highlighted in the text appear in the Glossary, at the end of the report.
Acronyms	When first used in this document, each acronym is expanded with the acronym in parentheses. A list of all acronyms used appears at the end of the document.
Regulations and Standards	Source references to regulations and standards consist of the acronym for the source organization and the number of the original code or standard (e.g., NFPA 130). All references are to the latest published editions, though they may not be the version adopted by the local or state regulatory authorities. Of course, the requirements in the latest versions take precedence. Transit agencies should identify the version currently used by the communities they serve, compare it with the corresponding passages quoted here, and determine whether they differ sufficiently to warrant obtaining the latest version. Quoted passages from regulations or standards are blocked, italicized, and identified by the logo of the source organization. Quotations are included from three organizations: the U.S. Department of Transportation (DOT); the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA); and the National Fire Protection Association (NFPA). Their logos appear in the list of graphic symbols, at the end of this document, as does the logo for the National Electrical Code, which appears in NFPA 70.

Graphic Symbols

In addition to the organizational logos used to identify quoted codes and standards, two symbols are used to highlight important information: (1) **additional information** and (2) **cautionary information**. Both of these symbols appear in the list of graphic symbols, at the end of this document.

Additional information is identified by a circled large lower case *i*; the information is bolded and enclosed in a box.

Cautionary information is identified by a large exclamation mark enclosed in a triangle with the word ***CAUTION*** below the triangle; the information is bolded.

Units of Measure

These are expressed in Standard International (SI) units (e.g., meters, kilograms, seconds, and Kelvin). The SI units used conform to the requirements of the Federal Standard 376 B, 1993 Edition. The equivalent in British units, where different from SI, is provided in parentheses. Units of measure appearing in a quotation are reprinted exactly as they appear in the quoted passage.

1.4 LIST OF STATUTES, REGULATIONS AND STANDARDS

Listed below are several Statutes, Regulations, Codes, and Standards that are relevant to the use of alternative fuel in buses. Not all of these have been cited or referenced in the following text. They are included as sources of additional information.

1.4.1 Statutes

- Clean Air Act Amendments, 1990, Title II, "Provisions Relating to Mobile Sources," PL 101-549.
- Energy Policy Act of 1992 (EPACT), Public Law 102-486.
- Alternative Motor Fuels Act of 1988 (AMFA), Public Law 100-494.

1.4.2 Regulations

Copies of the following regulations can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 or by calling (202) 783-3238.

- Code of Federal Regulations (CFR), Title 49, "Transportation." Part 171–Hazardous Materials Regulations. (U.S. DOT)
- Code of Federal Regulations (CFR), Title 40, "Protection of Environment." Part 86 – Control of Air Pollution from New and In-Use Motor Vehicles and New and In-Use Motor Vehicle Engines: Certification and Test Procedure. (U.S. EPA)
- Superfund Amendments and Reauthorization Act (1986), SARA Title III. (U.S. EPA)
- Code of Federal Regulations (CFR), Title 29. Part 1910 – Occupational Safety and Health Standards. (OSHA)

1.4.3 Standards

The following NFPA standards[(2)] can be obtained from the National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101 or by calling (800) 344-3555.

- NFPA 30A — Automotive and Marine Service Station Code. This standard applies to automotive and marine service stations and to service stations located inside buildings.
- NFPA 52 — Standard for ***Compressed Natural Gas*** (***CNG***) Vehicular Fuel Systems. This standard applies to the design and installation of ***CNG*** engine fuel systems on vehicles of all types including aftermarket and Original Equipment Manufacturers (OEMs) and to their associated fueling (dispensing) systems.
- NFPA 54 — National Fuel Gas Code. This code is a safety code that shall apply to the installation of fuel gas piping systems, fuel gas utilization equipment, and related accessories.

[(2)]The standards refer to the latest published edition where the date of publication is not specifically indicated.

- NFPA 57 — Standard for ***Liquefied Natural Gas*** (***LNG***) Vehicular Fuel Systems, 1996 Edition.

- NFPA 59A — Standard for the Production, Storage and Handling of ***Liquefied Natural Gas*** (***LNG***), 1996 Edition.

- NFPA 70 — National Electric Code. The purpose of this code is the practical safeguarding of persons and property from the ***hazards*** arising from the use of electricity.

- NFPA 88A — Standard for Parking Structures. This standard covers the construction and protection of, as well as the control of ***hazards*** in, open, enclosed, basement, and underground parking structures. This standard does not apply to one- and two-family dwellings.

- NFPA 88B — Standard for Repair Garages. This standard covers the construction and protection of, as well as the control of ***hazards*** in, garages used for major repair and maintenance of motorized vehicles and any sales and servicing facilities associated therewith.

- NFPA 497A — Recommended Practice for Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas. This recommended practice applies to locations where flammable gases or vapors, ***flammable liquids*** or combustible liquids are processed or handled and where their release to the atmosphere may result in their ignition by electrical systems or equipment.

The following standard can be obtained through the American National Standards Institute, Inc. or American Gas Association Laboratories, 8501 East Pleasant Valley Road, Cleveland, Ohio 44131.

- ANSI/AGA NGV2-1992 — Basic requirements for ***compressed natural gas*** vehicle (NGV) fuel ***containers***.

Chapter 2
Liquefied Natural Gas (LNG)

2.1 GENERAL PROPERTIES

2.1.1 *Physical Properties*

When methane (CH_4) gas is cooled to a temperature of 111.6 K (-259 °F), it liquefies at ambient pressure to a colorless, odorless liquid. Liquefaction of ***natural gas*** leads to the formation of ***liquefied natural gas*** (***LNG***). ***LNG*** consists primarily of methane, with minor quantities of ethane, propane, other higher hydrocarbons, nitrogen, and other components normally found in ***natural gas***. Methane volume fraction may vary between 95% to 99%. Table 2-1 shows a typical ***LNG*** composition.

Because of its low temperature, a spill of ***LNG*** onto any surface at room temperature results in rapid initial boiling of the liquid and emanation of ***natural gas*** vapors at the ***LNG*** boiling point temperature[3] (111.6 K or -259 °F). The boiling temperature varies with pressure. This variation is shown in Table 2-2. The critical temperature of methane is 190.6 K (-117 °F); hence, in order to maintain methane in a liquid state, even under pressure, the temperature must be lower than the critical temperature.

In buses, the ***LNG*** is carried in insulated vacuum jacketed, double wall, fuel tanks. Over a period of time, the pressure in the ***LNG*** fuel tanks will increase due to heat leak from the atmosphere. The construction of the tanks meeting the requirements of §2-3.5 of NFPA 57 is such that the ***fuel tank*** can withstand a pressure build up due to heat leak over a 72 hour period without venting and without jeopardizing the integrity of the tank. Generally, the relief valves on board the bus tanks are set to discharge vapor at a pressure of 1.03 MPa (135 psig). [The fueling station tank relief valves operate around 550 kPa (65 psig).]

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[3]Because the composition of ***LNG*** varies depending on the source of ***natural gas***, the boiling temperature at atmospheric pressure also varies slightly. Also, methane evaporates preferentially from ***LNG*** leaving a liquid which progressively becomes richer in higher hydrocarbons. This process, called "aging," occurs even when ***LNG*** is contained in an insulated vessel. The small heat leak over a prolonged period (several days) will "age" the ***LNG***.

Table 2-1
Typical LNG Composition

Hydrocarbon	Chemical Formula	Composition (Volume Percent)
methane	CH_4	95.30
ethane	C_2H_6	4.10
propane	C_3H_8	0.43
iso-butane	C_4H_{10}	0.04
n-butane	C_4H_{10}	0.04
iso-pentane	C_5H_{12}	0.01
n-pentane	C_5H_{12}	0.01
hexane	C_6H_{14}	0.05
nitrogen	N_2	0.02
TOTAL		100.00

Table 2-2
Selected Properties of Liquefied Natural Gas (LNG)*

Property	Property Values in SI Units	Property Values in Conventional Units
Boiling Temperatures** (at indicated pressures)		
101 kPa (14.7 psia); atmospheric pressure	111.6 K	-259.1 °F
150 kPa (~ 22 psia)	116.7 K	-250 °F
250 kPa (~ 36 psia)	123.9 K	-237 °F
350 kPa (~ 51 psia)	129.2 K	-227.4 °F
450 kPa (~ 65 psia)	133.9 K	-219 °F
Liquid Density at Boiling Point	425 kg/m^3	26.5 lb/cft
Density of Vapor at Boiling Point	1.84kg/m^3	0.115 lb/cft
(Relative density with respect to that of air at 293K)	(1.53)	(1.53)
Vapor ***Flammability Limits*** in Air†		
Lower Flammability Limit (LFL)	5% by volume	5.0
Upper Flammability Limit (UFL)	15% by volume	15.0
Heat of Vaporization of Liquid at Ambient Pressure	510.6 kJ/kg	219.5 Btu/lb
Heat of Combustion** (Lower Heating Value)	50 MJ/kg	21505 Btu/lb

* Values are obtained from ASHRAE Handbook (ASHRAE, 1969)

** Pure methane values are indicated.

† These values refer to a vapor-air mixture temperature of 298 K (77 °F). At lower vapor-air temperature, the UFL concentration decreases and the LFL concentration increases. For example, at a vapor-air temperature of 112 K (-260 °F) the LFL concentration for methane is about 5.8% by volume (Zabatekis, 1967).

The vapor released from the boiling of ***LNG*** at ambient pressure will consist, initially, of almost pure methane, followed, at later stages, with vapors containing a higher proportion of higher molecular weight hydrocarbons. The methane released will be cold and hence more dense than the ambient air. This vapor, when mixed with ambient air, **without the addition of any heat from other objects/ surfaces**, will remain heavier than air.

LNG vapor is cold and colorless. When this cold vapor mixes with humid air from the atmosphere, water vapor condenses providing the visible fog delineating the location of ***LNG*** vapor cloud. Also with the mixing of air and the consequent dilution, the methane vapor concentration in the vapor cloud decreases (from the initial value of 100%). Flammable concentrations can exist at the cloud edge. If the air has a relative humidity higher than 35%, the visible cloud encloses the flammable cloud within it. For humidities less than 35%, the flammable methane concentrations occur outside the visible cloud. Therefore, it should be noted that in dry conditions, flammable mixtures can exist outside the visible cloud. Some of the important thermodynamic properties of ***LNG*** are indicated in Table 2-2.

2.1.2 Dispersion of Vapors Generated from LNG Releases

The vapors generated by the evaporation of a pool of ***LNG*** are heavier than air. These vapors will be dispersed by the prevailing wind at ground level. Field tests have been conducted both in the U.S. and Europe to determine the dispersive behavior of ***LNG*** vapors. *(For a review of test data and mathematical models, see Havens, 1982.)* These tests indicate that the ***LNG*** vapor disperses very close to the ground and that maximum concentration of methane in a dispersing cloud occurs at or close to the ground, even in the case when the concentration is below LFL.[(4)] This behavior was found to be independent of wind speed. Many of the ***LNG*** vapor dispersion tests were conducted in a desert condition in China Lake, CA. The ground heat transfer to the vapor cloud over a significant time is considerable, yet no lifting of the cloud was observed. This indicates that the negative buoyancy effects are significant.

LNG in bus fuel tanks will be maintained at some pressure (1 to 2 atmospheres gage). When the liquid is released from pressure, it will flash forming both saturated methane vapor (at 112 K or -260 °F) and some droplet mist, both of which will be dispersed in much the same way as the pure ***LNG*** vapor—close to the ground. A part of the liquid at 112 K (-260 °F) may fall to the ground and evaporate due to boiling.

[(4)]For a 40 m^3 (10,570 gal) release of ***LNG*** at the rate of 10 m^3/min. (2,640 gal/min.) in a 4 m/s (9 mph) wind, the ground level concentration was above LFL for about 250 m (820 ft.) from the release point.

2.1.3 *Vapor Flammability*

Because of the very low temperature of ***LNG***, none of the ***natural gas*** odorization schemes are effective. The odorants have much higher boiling/evaporation temperatures compared to ***LNG*** components. Therefore, and because of the fractional distillation that ***LNG*** undergoes with time (with lower molecular weight methane being released first), the vapors released initially will be odorless even if odorants are added to the liquid.

2.1.4 *LNG Hazards*

LNG releases pose the following types of potential ***hazards***:

1. Thermal radiation from burning pools of ***LNG***.

2. Vapor fire caused by the ignition of an already developed (dispersed) vapor cloud.

3. Cold burns or metal embrittlement caused by physical contact with the liquid.

4. Asphyxiation in low lying areas (such as pits) into which the cold vapor may flow and preferentially displace the air.

5. Rapid Phase Transition explosions (a rare but potentially very damaging phenomenon).

Pool Fires. If ***LNG*** is released from a bus ***fuel tank*** onto the ground and the vapors produced are ignited immediately, a pool fire will occur. The shape of the pool base will depend on the shape of the containment area on the ground. Unconfined pools spreading on a level ground can be expected to burn with a near circular base. The size of the fire (height of the flames) will depend on the base pool size and the substrate on which the ***LNG*** is burning (i.e., ground or water) and wind conditions. In the case of ground, the evaporation rate of ***LNG*** is lower than on water and hence, will burn with a shorter height flame. The principal ***hazard*** from this type of fire is due to thermal radiation. It is estimated that the radial distance from the edge of the pool fire to a skin burn ***hazard*** zone is about 2.7 times the pool diameter. Data from pool and vapor fire field tests and the thermal radiation models are available in the literature *(Raj, 1982)*.

Vapor Fires. The ignition of an already developed/dispersed ***LNG*** vapor cloud ***in the open*** atmosphere results in the formation of a propagating fire ("turbulent deflagration"). The fire propagation velocity is several meters per second and increases with wind speed *(Raj & Emmons,* *1975).* The fire tends to propagate back to the source of the vapor. The fire ***hazard*** is limited to the size of the original vapor cloud. The thermal radiation ***hazard*** from the fire is limited to a few meters surrounding the vapor cloud.

Cryogenic Hazards. Exposure of human skin to ***LNG*** results in the skin tissue being frozen, i.e., a cold burn results. Prolonged exposure without the appropriate and immediate burn treatment will result in permanent damage to exposed skin areas.

Carbon steel structural members exposed to ***LNG*** will become very brittle. If the structural member is in tension it may fail or develop a crack, thus weakening the structure.

Asphyxiation. ***LNG*** vapor is not toxic, per se. However, ***LNG*** vapor displaces air from lower areas and could, therefore, pose asphyxiation ***hazard*** to human beings. Also, prolonged breathing of cold vapors can result in lung tissue damage.

Rapid Phase Transitions. A Rapid Phase Transition (RPT) explosion results when a colder, more volatile liquid superheats after coming in contact with a hot liquid. The temperature of the colder liquid increases with time. When this temperature reaches a critical value, termed the "superheat limit temperature," spontaneous homogeneous nucleation boiling occurs in a very short period of time (nanoseconds), resulting in an explosion. Serious, but localized, pressure shocks can result, destroying equipment and causing injury to nearby personnel. It should be noted that this phenomenon is not very common with ***LNG*** and requires the spill of ***LNG*** onto water. For details of this phenomenon, reference should be made to a GRI Publication *(Reid, 1982).* LNG-water RPTs have been observed in one of the field tests which destroyed the field equipment.

For additional information on LNG's properties and hazards, especially with respect to its use as a bus fuel (handling safety, proper procedures, etc.), the following technical reference(s) should be reviewed/consulted:

Murphy, M.J. "Properties of Alternative Fuels," Report No. FTA-OH-06-0060-94-1, Office of Research, Demonstration, and Innovation, Federal Transit Administration, Washington, DC 20590, October, 1994.

2.1.5 LNG Fuel Economy and Diesel Equivalence

In Table 2-3, the ***LNG*** fuel characteristics for use in buses are compared with those of ***diesel fuel***. ***LNG*** and ***CNG*** have about the same heating value per unit mass, since both fuels contain, predominantly, methane. However, since the density of ***LNG*** (a liquid) is higher than that of ***CNG*** by almost a factor of 2.3, the same thermal energy is carried in a smaller volume in ***LNG*** compared to that in ***CNG***.

The ***LNG*** tank sizes on buses vary depending on the size of the bus. The water volumes of bus ***LNG*** tanks vary between 340-570 liters (90-150 gallons). The useable ***LNG*** volume is typically about 85% of this volume. The tanks are generally made of high ductility austenitic steels and operate over pressures 300-500 kPa (30-60 psig).

The heating value of ***LNG*** (per unit mass) is about the same as that of diesel; however, its density is about one-half of diesel. Hence, for the same duty cycle, about twice the volume of ***LNG*** needs to be carried in buses. Table 2-3 shows the diesel equivalence volume of ***LNG***. Operating experience data from ***LNG*** buses have been published *(Motta, et al., 1996)*. These data include miles per diesel gallon equivalent, and fuel and maintenance costs per 100 miles, among other items.

2.1.6 LNG Supply Quality

The methane content of ***LNG*** can vary depending on the source of ***natural gas*** as well as the duration of aging that the liquid has undergone in storage. Ultra-pure ***LNG*** (with a methane content of 99% and above) is available and is called Refrigerated Liquid Methane (RLM). The quality of ***LNG*** to be used depends on the engine specifications. It is recommended that a transit agency proposing to use ***LNG*** buses review the engine specifications carefully and then contract for ***LNG*** delivery with the required range of methane content. The effect of variation in methane content on the engine performance and mileage also needs to be taken into consideration when specifying the ***LNG*** quality.

Table 2-3
Diesel Equivalent Values

1. LOWER HEATING VALUES (LHV)†				
Fuel	**SI Units**		**Conventional Units**	
	Value	**Units**	**Value**	**Units**
Diesel #1	35,120	MJ/m^3	126,000	Btu/gal
	41.3	MJ/kg	17,760	Btu/lb
Diesel #2	36,235	MJ/m^3	130,000	Btu/gal
	42.6	MJ/kg	18,330	Btu/lb
Liquefied Natural Gas (LNG)	20,904	MJ/m^3	75,000	Btu/gal
	49.2	MJ/kg	21,150	Btu/lb
Compressed Natural Gas (CNG)	36.15	MJ/m^3 (std)	970	Btu/SCF

2. DIESEL VOLUME EQUIVALENCY (DVE) FOR LNG ††				
Fuel	**SI Units**		**Conventional Units**	
	Value	**Units**	**Value**	**Units**
DVE #1 ‡	1.68	litre/litre	1.68	gal/gal
DVE #2 ‡	1.73	litre/litre	1.73	gal/gal
500 liters of #1 diesel	935 *	litres of LNG	—	—
125 gallons of #1 diesel	—	—	235 *	gal of ***LNG***

† Based on the assumptions: ***LNG*** density = 425 kg/m^3 and diesel density = 850 kg/m^3

†† The values presented in this table are to be read as follows. For example, the DVE with #1 diesel is represented as 1.68 litre/litre. That is, 1.68 litres of ***LNG*** are equivalent to 1 litre of diesel when evaluated on the same (lower) heating value equivalency basis.

‡ Based on the theoretical LHV energy equivalence of Diesel #1 and Diesel #2, respectively, with ***natural gas***.

* This equivalency value is based on the assumption that a ***natural gas*** engine will be 10% less efficient than its diesel counterpart (on energy equivalence basis). This number indicates the volume of ***LNG*** that must be carried on-board an ***LNG*** bus to obtain the same operating range as a bus carrying the stated volume of diesel.

2.2 FUELING FACILITIES

The physical and operational requirements of an ***LNG fueling facility*** in a bus transit system are discussed in this section. An ***LNG fueling facility*** consists of two principal parts: the ***LNG*** storage tank and the ***LNG*** dispensing unit(s). Associated with the storage tank will be the ***LNG*** cargo unloading station.

The general governing standard for the design of a vehicular ***LNG fueling facility*** is NFPA 57. The 1996 Edition of NFPA 59A also addresses the requirements for Vehicle Fueling for Industrial and Commercial Facilities Using ASME ***containers***. NFPA 57 standards are relatively recent and many states may not have adopted these standards. Other standards, such as the Uniform Fire Code (UFC), Building Officials and Code Administrators (BOCA) fire code, Southern Building Code Congress International (SBCCI), etc., should also be reviewed to determine their possible applicability, to ***LNG*** fueling station design. Where there are specific state or local regulations applicable to ***LNG*** fueling stations, they should be followed. It is advisable to consult with and involve local and state regulatory agencies during the early stages of an ***LNG*** facility's design. In some instances, the building and fire insurance companies may pose additional requirements. A transit agency should consult with its insurance carrier and determine which codes, standards, and requirements are necessary for compliance.

__LNG__ facilities including plants and storage which are part of the infrastructure of __natural gas__ transportation in pipelines come within the purview of the __Natural Gas__ Pipeline Safety Act of 1968. The safety requirements for such __LNG__ plants are specified in:

49 CFR, Part 193: Liquefied Natural Gas Facilities; Federal Safety Standards

The following national codes are applicable specifically to one or more elements of an **LNG** facility.

NFPA 57:	*Standard for **Liquefied Natural Gas** (**LNG**) Vehicular Fuel Systems (1996 Edition)*
NFPA 70:	*The National Electric Code (1996)*
NFPA 59A:	*Standards for the Production, Storage, and Handling of **Liquefied Natural Gas (LNG)**, 1996.*

*The 1996 Editions of NFPA 57 and NFPA 59A have been coordinated to make the two standards mutually consistent, except for minor differences (e.g., Chapter 4 of NFPA 57 and Chapter 10 of NFPA 59A). Previous editions of NFPA 59A did not address storage of less than 265 m^3 (70,000 gallon) **of LNG** in a tank. This has been rectified in the 1996 Edition.*

2.2.1 LNG Storage Area

LNG storage ***containers*** form an important element of the ***LNG fueling facility***. Because of the large quantity of ***flammable liquid*** which will be stored in these tanks, a number of safety requirements have to be considered. These considerations include the size of tanks, materials of construction, location of tanks from the property line, distance between adjacent tanks, and safety systems.

Storage Tanks. An *LNG* storage tank is generally of a double-wall construction with the inner tank constructed of welded high ductility austenitic steel and the outer tank made of carbon steel. The *LNG* is contained in the inner tank which is surrounded by insulation contained within the outer tank. The *LNG* containing tank has to conform to the ASME Boiler and Pressure Vessel Code and should be ASME-stamped.

LNG storage tanks in a transit facility are generally of the fixed type. That is, the *LNG* storage tank is a permanent structure constructed on-site. However, smaller transits with very few *LNG* powered buses can have an *LNG* storage trailer as a storage medium.[5]

[5]Maryland Mass Transit Administration's *LNG* bus demonstration project at a Baltimore facility uses this concept of *LNG* storage.

NFPA 57 Chapter 4 stipulates the tank construction and other requirements for ***LNG*** tanks of capacity 265 m^3 (70,000 gallons) or smaller.[6] This NFPA Chapter covers the functional specifications for such equipment and appurtenances as internal and external piping, ***container*** materials of construction, product retention valves, piping measuring instruments, among other equipment. In addition the ***container*** seismic design, foundation, support, and location of tanks relative to other property are specified.

For example, the minimum separation distances to buildings and property lines are indicated in NFPA 57 as follows:

NFPA®

Table 4-5.1 Distances from Impoundment Areas to Buildings, Property Lines

Container water capacity (gal)	***Minimum distance (ft) from edge of impoundment or container drainage system to buildings, property lines***	***Minimum distance between storage containers (ft)***
Less than 125	*0*	*0*
125 to 500	*10*	*3*
501 to 2,000	*15*	*5*
2,001 to 15,000	*25*	*5*
15,001 to 30,000	*50*	*5*
30,001 to 70,000	*75*	*¼ the sum of the diameters of adjacent* ***containers*** *(5 ft minimum)*

The ***LNG*** tank should be provided with an internal submerged or external cryogenic pump to supply ***LNG*** to the dispensing unit. Other unique designs which utilize gravity feed and pressure developed by heat leak into the liquid to pump the liquid are also in use.[7] The latter design may be useful for smaller facilities with a limited number of vehicles to service.

[6]The requirements for ***LNG*** tanks with volume greater than 265 m^3 (70,000 gal) are covered in NFPA 59A.

[7]This pumpless design is used by the ***LNG*** facility at the Greater Austin Transportation Company.

The liquid extraction system should also provide for the return of the vapor from the vehicle into the vapor space in the storage tank. In addition, all ***LNG*** tanks used in transit systems should comply with the following NFPA 57 requirements for the provision of product retention valves.

NFPA®

4-6 Product Retention Valves. *All liquid and vapor connections, except relief valves and instrument connections, shall be equipped with automatic fail safe product retention valves. These automatic valves shall be designed to close on the occurrence of any of the following conditions:*

(a) Fire detection or exposure.

*(b) Uncontrolled flow of **LNG** from the **container**.*

(c) Manual operation from a local and remote location.

*Connections used only for flow into the **container** shall be permitted to be equipped with two back flow valves, in series, in lieu of the above requirements. The appurtenances shall be isolated as close to the **container** as practical so that a break resulting from external strain shall occur on the piping side of the appurtenance while maintaining intact with the valve and piping on the **container** side of the appurtenance.*

For other requirements on tank inspection, testing and purging, instrumentation, pressure control, and piping, Chapter 4 of NFPA 57 should be consulted.

LNG Tank Siting and Spill Containment. A number of considerations, both safety and geographic, dictate the location of ***LNG*** tanks within a transit facility. ***LNG*** tanks must be provided with impoundment to contain any ***LNG*** that may be spilled. The tank siting and impoundment requirements are indicated in §3-2.2 and §3-2.3 of NFPA 57. These sections should be reviewed carefully before an ***LNG*** tank siting and construction are undertaken. Specifically, the following important requirements must be followed.

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3-2.2.2 *If other combustible or hazardous liquids can encroach on the LNG fueling facility, means shall be provided to protect that facility.*

3-2.2.4 *Points of transfer shall be located not less than 25 ft. (7.6 m) from the nearest important building not associated with the LNG facility, or from the line of adjoining property that can be built upon, or from fixed sources of ignition.*

3-2.3.3†* *Impounding areas, if provided to serve LNG transfer areas, shall have a minimum volumetric capacity equal to the greatest volume of LNG or flammable liquid that could be discharged into the area during a 10-min period from any single accidental leakage source or a lesser time period based upon demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction.*

3-2.3.4 *Flammable liquid storage tanks shall not be located within an LNG container impoundment area.*

3-2.3.5 *Impounding areas serving LNG containers shall have a minimum volumetric holding capacity "V," including any useful holding capacity of the drainage area and with allowance made for the displacement of snow accumulation, other containers, and equipment, in accordance with the following:*

(a) For impounding areas serving one, or more than one, container with provisions made to prevent low temperature or fire exposure resulting from the leakage from any one container served from causing subsequent leakage from any other container served, the volume of the dike shall be the total volume of liquid in the largest container served, assuming the container is full.

(b) For impounding areas serving more than one container without provisions made in accordance with (a), the volume of the dike shall be the total volume of liquid in all containers served, assuming all containers are full.

The area within the impoundment basin should be monitored for methane concentrations by providing hydrocarbon sensors within the impoundment areas. The importance of such a monitoring system becomes high if the impoundment walls are high, serviceable equipment are located within this "high" ***dike*** and service personnel enter the diked area.

2.2.2 LNG Dispensing Area

The second component of an ***LNG fueling facility*** is the fuel dispensing unit or area. Because of the frequent connect and disconnect operation in a fuel dispensing area, the probability of fuel release is higher than in any other part of the ***fueling facility***. The design codes have recognized this potential vulnerability and have therefore stipulated the provision of appropriate safety systems. The increased level of ***risk*** at the fuel dispenser can be somewhat mitigated by the presence of one or more trained persons while the vehicle fueling operation is underway.

There are basically two locations of fueling areas, namely:

- outdoor fueling
- indoor fueling

In both types, the filling time of a vehicle tank is relatively short, of the order of minutes. Therefore, the ***LNG*** flow rate through the dispenser will be high; 75-200 L/min (~ 20-50 gpm).

While the standards allow either scenario, there is often considerably more design effort and cost associated with indoor fueling. Outdoor fueling is a preferred method because of less ***hazards*** of gas accumulation in case of a fuel release. However, outdoor fueling may not be acceptable to transit employees in cold climates because of the human discomfort in performing fueling operations in wintry conditions.

2.2.2.1 Outdoor Fueling

Design Overview—Outdoor Fueling. The principal criteria in designing an *LNG* dispensing system are to minimize the ***risk*** to personnel and facility by preventing the liquid release, reduce the gas concentration in case of liquid release and its evaporation, control the movement of the gas, reduce the occurrence of sources of ignition near the dispensing unit, and provide adequate gas sensing and warning/alarm systems.

The general requirements for fueling stations are specified in NFPA 57 §3.2. Some of the important requirements in this standard for dispensing systems are as follows:

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3-4.1 Fuel Dispensing Systems.

3-4.1.1 *The dispensing device shall be protected from vehicle collision damage.*

3-4.1.2 *An emergency shutdown system (ESD) shall be provided that includes a shutoff valve for stopping liquid supply and shutting down transfer equipment. An actuator, distinctly marked for easy recognition with a permanently affixed, legible sign, shall be provided near the dispenser and also at a safe, remote location.*

3-4.1.3 *The maximum delivery pressure at the vehicle tank inlet shall not exceed the maximum allowable pressure of the vehicle fuel tanks.*

3-4.1.4 *Hoses and arms shall be equipped with a shutoff valve at the fuel end, and a breakaway device to minimize release of liquid and vapor in the event that a vehicle pulls away while the hoses remain connected. Such a device shall be installed and maintained in accordance with manufacturer's instructions.*

3-4.1.5 *When not in use, hose shall be secured to protect it from damage.*

In addition, the fueling connector should be equipped with an interlock device which prevents *LNG* release when the hose is filled with liquid. Also, a bleeding or vent connection needs to be provided in the loading arm or hose so that they can be depressurized after a liquid transfer operation.

After the completion of a liquid transfer and the nozzle is removed from the vehicle receptacle, frost can form on the delivery nozzle surface due to its very cold temperature. If another vehicle filling operation is scheduled very soon, it is necessary to remove the frost from the nozzle face (otherwise a leak tight connection with the vehicle receptacle may not occur) with high pressure air or nitrogen. Therefore, one of the important appurtenances that should be provided at an ***LNG*** dispenser is high pressure dry cleaning air or dry nitrogen. The flow control valves of the ***LNG*** storage tank and on the dispensing equipment should, preferably, be operated pneumatically using dry nitrogen gas. Such an inert gas pneumatic system offers considerable safety advantages over air operated or electrically operated valves. Use of dry nitrogen also eliminates potential problems associated with icing at the valves.

Electrical Equipment—Outdoor Fueling. In general, all electrical equipment and wiring used in the dispensing area should conform to the requirements of NFPA 70 and be consistent with Class I, Group D Division. The classes of electrical equipment at various locations in a fueling area are indicated in NFPA 57, Table 3-12.1. This table is reproduced below.

NFPA®

Table 3-12.1 LNG Fueling Facility Electrical Area Classification

Part	***Location***	***Class I, Group D Division[1]***	***Extent of Classified Area[2]***
A	***LNG Fueling Facility Container Area***		
	Indoors	1	*Entire room.*
	Outdoors, above ground containers. (Other than portable.)	1	*Open area between a high-type dike and container wall where dike wall height exceeds distances between dike and container walls.*
		2	*Within 15 ft (4.6 m) in all directions from container, plus area inside a low-type diked or impounding area up to the height of the dike impoundment wall.*
	Outdoor below ground containers.	1	*Within any open space between container walls and surrounding grade or dike.*
		2	*Within 15 ft (4.6 m) in all directions from roof and sides above grade.*

Part	Location	Class I, Group D Division[1]	Extent of Classified Area[2]
B	**Nonfired LNG Process Areas Containing Pumps, Compressors, Heat Exchangers, Piping, Connections Vessels, etc.**		
	Indoors with adequate ventilation.	2	Entire room and any adjacent room not separated by a gastight partition, and 15 ft (4.6 m) beyond any ventilation discharge vent or lower.
	Outdoors in open air at or above grade.	2	Within 15 ft (4.6 m) in all directions from this equipment.
C	**Pits, Trenches or Sumps Located in or Adjacent to Division 1 or 2 Areas**	1	Entire pit, trench, or sump.
D	**Discharge from Relief Valves, Drains**	1	Within 5 ft (1.5 m) from point of discharge.
		2	Beyond 5 ft (1.5 m) but within 15 ft (4.6 m) in all directions from point of discharge.
E	**Vehicle/Cargo Transfer Area**		
	Indoors with adequate ventilation.[3]	1	Within 5 ft (1.5 m) in all directions from point of transfer.
		2	Beyond 5 ft (1.5 m) of entire room and 15 ft (4.6 m) beyond ventilation vent.
	Outdoors in open air at or above grade.	1	Within 5 ft (1.5 m) in all directions from point of transfer.
		2	Beyond 5 ft (1.5 m) but within 15 ft (4.6 m) in all directions from the point of transfer.

[1] See Article 500 — "Hazardous (Classified) Locations" in NFPA 70 for definitions of Classes, Groups, and Divisions.
[2] The classified area shall not extend beyond an unpierced wall, roof, or solid vapor tight partition.
[3] Ventilation is considered adequate when provided in accordance with the provisions of this standard.

Other design requirements are specified in NFPA 57 §3-12. Some of these requirements are indicated below:

- Protection against static electricity discharge should be provided by designing an electrical ground strap cable that can be attached to the metallic body of the vehicle.

- Proper seals should be provided between flammable fluid systems and electrical conduits/wiring, connections, heating coils, pumps, blowers, etc., to prevent potential penetration of flammable vapors and their subsequent ignition by electrical equipment.

Heating and Ventilation in the Fueling Area—Outdoor Fueling. In many outdoor ***LNG*** fueling facilities there will be no heating or powered ventilation systems. NFPA 57 does not indicate any requirements or specifications for this type of equipment for use in a ***fueling facility***.

If heaters need to be provided near a dispensing unit, it is prudent practice to design space heaters in such a way that they do not pose an ignition problem. For example, in some designs a safe haven cubicle may be provided near the fuel dispenser for the safety and comfort of the fueler. This cubicle may be heated with an open coil electrical heater. In such a design the cubicle should be positively pressurized with air so that any gas leak doesn't penetrate into the cubicle. Temperature of any heated surface should not exceed 700 K (800 °F). It should be noted that ***LNG*** vapor is heavier than air and therefore will tend to disperse close to the ground. Hence, all ignition sources at or close to the ground should be removed from the immediate vicinity of the dispenser.

2.2.2.2 Indoor Fueling

Indoor fueling areas are allowed to be built and operated provided they are built according to NFPA 57 §3-2.4 requirements. Specifically, the building must be used exclusively for ***LNG*** dispensing and be constructed of non-combustible materials. Other important considerations in the design of an indoor facility include:

- Ventilation
- Gas detection instruments
- Fire protection
- Electrical systems and equipment
- Warning and alarm systems

NFPA 57 §3-2.4 should be carefully reviewed and all its design requirements should be implemented. Some of the important requirements include:

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3-2.4.3 *Ventilation shall be by a continuous mechanical ventilation system or by a mechanical ventilation system activated by a continuously monitoring natural gas detection system when a gas concentration of not more than one fifth of the lower flammable limit is present. In either case, the system shall shut down the fueling system in the event of failure of the ventilation system.*

__3-2.4.4__ The ventilation rate shall be at least 1 ft^3/min per 12 ft^3 (1 m^3/min per 12 m^3 of room volume).

> *NOTE: This corresponds to five air changes per hour.*

__3-2.4.6__ A gas detection system shall be provided in all buildings containing LNG and shall activate an alarm when a maximum of 20 percent of the lower flammable limit is reached. The alarm shall be clearly audible and visible both inside and outside the affected area.

A gas detection system should be provided in the ***fueling facility*** and it should be tied to an alarm system which will be activated if "one-fifth of ***lower flammability limit*** is reached" (NFPA 52, §4-4.3.6). It is also desirable to build in certain other ***fail-safe*** systems such as:

- reactivation of fueling system only by a manual override after an alarm;
- shutdown of the fueling system if the ventilation system fails in an indoor facility; and
- increased ventilation flow following the detection of 20% LFL concentrations.

It is uncertain whether normal ventilation flow in a facility will be sufficient to sweep out of the building all gas pockets containing flammable concentrations of ***natural gas***. In some facilities, the ventilation rate is increased, by about a factor of two above the normal rate, when a sensor detects 20% of the LFL concentration of ***natural gas***. A transit agency should consult with its A&E contractor and design the appropriate level of ventilation for both normal operation and emergencies involving accidental gas release within a facility. It should be noted that in the event of a large and rapid release of gas, it may not be practical or possible to ensure that gas concentrations are maintained below LFL.

NFPA 57 does not specify the type of equipment required within the fueling area, although it does indicate the minimum level of ventilation.

Electrical Equipment—Indoor Fueling. The guiding principle in the design of an electrical system in an ***LNG fueling facility*** (where the potential for an ***LNG*** leak followed by its vaporization and formation of flammable vapors exist) is to eliminate all ignition sources within the facility. Where such complete elimination is not possible, the electrical (wiring and equipment) design should reduce the potential for ignition. The design may consider any or all of the strategies involving structural modifications, equipment redesign, positive air/nitrogen flow approach, electrical shutdown ***controls***, among other issues. That is, both passive designs of ***ignition source*** removal or active, real-time shutdown of electrical and high temperature systems should be considered.

However, where there are specific local or national code requirements, they should be followed in the design.

Other requirements for electrical systems presented in the section on outdoor ***fueling facilities*** should be considered equally applicable to an indoor facility.

To be consistent with the electrical area classification requirements and with the general aim to control the presence of ignition sources and the concentration and movement of a potential gas plume, the following should be considered:

1. Ignition sources or hot objects should be eliminated from areas close to the ground and from other areas through which the vapors emanating from an ***LNG*** release may travel.

2. Heaters should not pose ignition potential. They should be either electrically classified (Class 1, Division 1) or indirect (forced air) gas fired or steam or hot water, or direct vent combustion type with the exception of non-recirculating roof top (outdoor) direct fired make-up air units. Non-sparking blades, made of aluminum or plastic, should be used in ventilation fans.

3. The temperature of any surface which could contact the gas must not exceed 700 K (800 °F).

4. The ventilation system should be such that any air flow is always from the garage to outside. That is, the garage should be at a higher pressure relative to the outside air. If the garage and indoor ***fueling facility*** are connected, then the garage pressure should be higher than that of the fuel facility to ensure that any gas released at the ***fueling facility*** does not enter the garage.

5. A source of fresh air should be provided to human occupancy areas adjacent to the fueling room and maintaining this area at a positive pressure relative to the maintenance and storage areas. Rest rooms located adjacent to the fueling area should be electrically classified.

2.2.3 LNG Cargo Transport Unloading Area

LNG transported to the facility is unloaded in this area to the ***LNG*** storage tanks. In most cases, ***LNG*** will be transported in highway trucks. The nature of the operation in ***LNG*** unloading requires connecting and disconnecting transfer lines every time the storage tank is replenished. Because of these make and break connections the ***risk*** of accidental release of ***LNG*** is high. Also, because of the high rates of pumping the quantity released, if a break occurs, will be large. Hence, the unloading system and the associated plumbing and control equipment have to be designed carefully and the transfer operation should be conducted with care. The design requirements for the ***LNG*** cargo transfer facility are indicated in §3-3 of NFPA 57.

The principal objective of a cargo transfer terminal design is to ensure that safety interlocks are provided to reduce or eliminate the possibility of ***LNG*** release due to either mechanical failure or human error. Particular attention, therefore, needs to be paid to the following design issues.

1. Prevention of overpressurization of the ***LNG*** storage tank.

2. Provision of isolation valves, check valves, and automatic shutoff valves; not only to shutoff the flow, but also to minimize the volume of liquid released in case of pipe break or transfer hose disconnect.

3. Provision of bleed or vent connections in the transfer piping or loading arms to depressurize the system prior to disconnection.

4. Prevention of truck pull away when the liquid transfer is taking place.

5. Elimination of ignition sources in and around the transfer terminal.

6. Providing adequate instruments to monitor the pressure and liquid level in the receiving tank, gas concentrations, and other operating status indicators.

It is noted that the ***LNG*** flow rate during the transfer operation (between the truck and the storage tank) will be high. Therefore, it is necessary to design fast acting shut-off and isolation valves to minimize the quantity of ***LNG*** release in the case of a pipe rupture or disconnection. The piping and supports should be designed to withstand, without rupture, the water hammer generated stresses during a rapid shut-off of flow.

NFPA 57 §3-3 should be reviewed carefully and all its requirements should be implemented in the design. The following important requirements are excerpted from NFPA 57.

NFPA®

3-3.2 *When making transfers into fueling facility containers, the LNG shall be transferred at a pressure that shall not overpressurize the receiving tank.*

3-3.3 *The transfer piping shall have isolation valves at both ends. On facility containers with a capacity greater than 2,000 gal (7.6 m^3), one remotely operated valve, automatic closing valve, or check valve shall be used to prevent backflow.*

3-3.4 *If the fueling facility tank or transfer equipment is located in a remote area, operating status indicators, such as those that indicate container level, shall be provided in the unloading area.*

3-3.5 *At least one qualified person shall be in continuous attendance and shall have an unobstructed view of the transfer point while unloading is in progress.*

2.2.4 Safety Control Systems

NFPA 57 requires the provision of a combustible gas detection system in indoor fueling stations which will trigger an audible alarm in the event of detection of a ***natural gas*** concentration of 20% LFL. (Refer to NFPA 57 §3-2.4.6.) To enhance safety, it is prudent practice to provide, in addition to the above, the following:

1. A combustible gas detection system (in an indoor ***fueling facility***) integrated into the other ***controls*** such that upon detection of combustible gas at 20% LFL (Stage 1 alarm), the door to the outside will be opened in the fueling area, any inside partitions will be closed, ventilation will be increased to a higher rate, an audible and visual alarm will be activated, all fueling operations (all fuels) and fuel pumps will be shut down and a remote alarm will be sent to an on-site dispatcher.

2. An alarm (Stage 2 alarm) when the gas detector senses 50% LFL. The entire facility should be put on alarm and all but safety personnel should be evacuated. The local fire department should be called by the dispatcher, or by a direct, automatic, central station connection.

3. A centralized emergency shutdown (***ESD***) system at the ***LNG*** station which upon activation will terminate dispensing, close all automatic valves on the storage lines, shut down all liquid pumps and isolate the fueling lines and ***LNG*** tank. This system should be ***fail-safe*** and should be designed to require a manual reset.

   ESD buttons should be provided at each dispenser and at all exits from the fueling area. An ***ESD*** button and a signal of ***ESD*** activation should be located in the transit agency dispatcher's office.

Fire Protection. A fire protection system is an essential part of an ***LNG fueling facility***. This system is required to be provided under the NFPA 57 §5-2 standards. The requirements of a fire protection system include the provision of:

- equipment and sensors to detect and control fires (and leaks of ***LNG***, flammable refrigerants, and flammable gases or liquids); and

- methods necessary to protect vehicles, equipment, and structures from the detrimental effects of fire.

The fire detection sensors/instruments should be located close to the ***LNG*** tank and fuel dispensing units. Instruments such as ultraviolet and infrared detectors are commonly used for detecting fires. These sensors should be integrated into the general facility alarm system. If a fire is detected, the control system should automatically shut down all fuel transfer operations and isolate the ***LNG*** tank and dispensing equipment.

The fire protection system design should incorporate a fire suppression system which is activated automatically when the sensors detect a fire. The suppression system must have the capability and capacity to smother an ***LNG*** fire either in the tank ***impoundment area*** or at the dispenser.[(8)] Proper safeguards should be built into a chemical extinguishing system such that false signals from the detectors are ignored and the deluge system not operated. A fire extinguisher deluge system override button should be provided in the fueler kiosk to prevent the extinguisher release in response to false alarms.

2.2.5 Dispensing Area Operations and Procedures

Existing codes do not address the operational aspects of the fueling area in detail. NFPA 57 specifies some signage requirements as do several of the local codes. In addition, it is prudent practice to enforce the following procedures in a ***fueling facility***:

1. Strictly prohibiting smoking, use of open flame or spark (including jumper cables) or any other source of ignition in the fueling area.

2. Training the personnel working in the fueling area in the proper way to dispense fuel, following carefully restart procedures and emergency procedures. If local regulations

[(8)]One transit system employs a 900 kg (2,000 lb) dry chemical extinguishing system. Upon detection of a fire, the system sprays 900 kg of dry powder over the entire refueling area in about 30 seconds.

require additional training or certification this should be regarded as the minimum training requirement.

3. Enforcing the wearing of hand gloves capable of withstanding ***LNG*** splashes (and ***LNG*** temperature) by the person fueling a vehicle.

4. Requiring the shut-off of the bus engine prior to fueling, and applying the parking brake. If a vehicle is parked on any incline or the brakes are not fully locked, the wheels of the bus should be chocked.

5. Developing and implementing an employee evacuation plan to be used in cases of 20% LFL alarms (or other emergencies).

6. Avoiding the performance of any type of service or repair to the bus while it is parked in the fueling area (with the exception of normal fluid level and tire pressure inspections and cleaning).

7. Keeping a bus with a known leak outside. If a bus inside a garage springs a leak, it should be moved outside if it is safe to do so, until it can be defueled, and the leak isolated. A bus with a known leak should never be fueled.

8. Posting clearly visible signs indicating NO SMOKING and IGNITION OFF as well as the location of all ***ESD*** buttons and FIRE pulls in and around the fueling area.

9. Training the employees to activate ***ESD*** as the first line of action in the event of an ***LNG*** leak or any other incident. The area should then be evacuated.

10. Establishing a good electrical ground between the bus and the fuel dispenser prior to fueling a bus.

2.2.6 Maintenance of Safety Equipment

Regular maintenance of instruments and equipment should be performed. As a minimum, this maintenance should include:

1. Testing and calibration of combustible gas detection and fire systems should be undertaken at manufacturer specified intervals.

2. Regular testing and calibration of ***LNG*** flow measuring systems should be undertaken.

3. Regular testing and calibration of alarm systems and the ***LNG*** flow shutdown system should be conducted.

4. Regular inspection of ventilation system components and the response to gas detection in an indoor facility (i.e., opening doors and increasing ventilation rate).

Facilities should also undergo a fire prevention inspection. This fire prevention inspection should include all devices which are commonly inspected in transit garages, such as:

- All sprinkler valve assemblies (monthly inspection).

- Yard hydrants and hoses, inside hoses and portable fire extinguishers (monthly inspection). Electrical equipment and storage of flammable liquids should be checked monthly.

- Housekeeping, as well as cutting and welding, smoking regulations, sprinkler alarms and doors at cut-off walls (monthly inspection).

- Operational capability and readiness of systems to verify triggering, interlocks, and automatic ***controls*** (threshold should be checked with a simulated gas release event).

Weekly inspections should include:

- General condition of automatic sprinkler heads

- Dry pipe valves

- Water supplies

- Locked valve shut-offs

In addition to the above, energy systems for ventilation and electrical should be checked monthly. A calibration of ***natural gas*** detectors should be done on a six-month interval or per manufacturer's recommendations, whichever is more frequent. Infrared and ultraviolet fire sensors should be inspected regularly.

2.3 BUS STORAGE FACILITY

A bus storage facility is a building in which buses are parked for long periods of time (12 hours or more) when the buses are not in service.[9] The storage facilities for buses have several common features, irrespective of the fuel used, such as exhaust fume ventilation, fire detection and suppression systems, and traffic flow management/control systems, among other features. However, special design requirements may need to be implemented depending on the nature of the fuel used, especially if the fuel is ***LNG***, ***CNG***, or ***LPG.*** In this section, the design requirements for an ***LNG*** bus storage facility are discussed.

NFPA 88A ("Parking Structures") standards are not specifically applicable to transit bus storage facilities. However, NFPA 88A is the only standard which defines dead storage facilities. Buildings meeting the NFPA 88A definition of a parking facility are discussed in this section. Storage facilities, parts of which may serve as a bus maintenance shop, do not come within the purview of this section. They are discussed in Section 2.4 of this document.

2.3.1 Design Overview (Storage Area)

A principal phenomenon which has bearing on the design of the storage/parking facility is the heat leak into the ***LNG*** tank on board the bus and the resultant pressure rise. Distinction needs to be made, therefore, between "short-term" parking (typically less than a day) and "long term" parking (several days). Potential safety problems may arise during short-term parking from fuel system component failures due to malfunction, component wear, or external forces such as collision or fire. Safety problems associated with long-term storage could arise if the excess tank pressure is not relieved or the ***natural gas*** released during tank relief is not properly dissipated.

The overall design strategy should be to avoid the release of ***natural gas*** from stored buses or if excess pressure occurs the gas should be properly exhausted to the environment. Also, the facility design should eliminate all ignition sources within the storage facility. Finally, the design should consider the effect of human failures, and, to the extent possible, anticipate potential problems and provide (in the facility design) adequate factors of safety.

Short Term Storage Facility Design Issues. The following features must be considered when designing or modifying a facility to store ***LNG*** buses for relatively short periods.

1. Parking ***LNG*** buses in a separate and dedicated area, if the facility is shared with buses fueled by other fuels (diesel, gasoline, alcohols, etc.).

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[9]In certain warm climatic regions of the U.S., transit buses are stored outside. Outdoor parking does not present a significant safety concern; hence it is not discussed in this document.

2. Providing methane concentration sensors ("hydrocarbon sensors") close to the floor level in addition to providing them either at the ventilation exhaust fan intake or in ceiling joists.[10]

3. Including in the design a means of handling or removing an ***LNG*** leaking bus from the parking area without posing an ignition problem (i.e., not using mechanical or electrical equipment that may spark or present a high temperature surface).

Other common design considerations are discussed in later subsections.

Long-Term Storage Facility Design Issues. The ***LNG*** tanks on the buses are generally designed for a "hold time" of about 5 days.[11] A loss of vacuum in the jacket or the loss of tank insulation can drastically increase the rate of heat transfer to the inner tank and result in a corresponding reduction in the holding time, by almost a factor of 10. Therefore, consideration should be given to providing exhaust hose connections to the vapor space of LNG tank to safely exhaust to the atmosphere the vapors released due to excess pressure relief valve operation. The alternative is to park the LNG buses outdoors. The last option is to remove ("defuel") all LNG from the tanks before the vehicle is stored for a long duration.

2.3.2 Electrical Equipment

In an ***LNG*** bus storage facility, the presence of ignition sources are of primary concern. Surface temperatures above 700 K (800 °F) or exposed flames must be eliminated. Spark generating equipment should be de-energized upon detection of a gas leak. It should be noted that the effectiveness of this strategy is very dependent on the quickness with which the presence of ***natural gas*** is detected. Devices which are potential sources of ignition in the travel path of the gas should be investigated and appropriate design solutions should be developed. These may include removing the potential ignition sources, modifying the characteristics of the equipment so that they no longer pose ignition potential, or designing active shut-off strategies when a release is sensed.

At present, the requirements for electrical ***system safety*** in ***LNG*** bus garages are not available in any national code. However, prudent design of a garaging facility's electrical system should adopt the electrical equipment requirements of NFPA 57 for a ***fueling facility***, and applicable parts of NFPA 70. A facility design should take into account special safety features that may be provided on the

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[10] In general, ***LNG*** buses are provided with hydrocarbon vapor concentration sensors. However, these sensors are not always connected or in communication with the building alarm and annunciation system. It is prudent to investigate the feasibility of interfacing the bus-based hydrocarbon sensors with the facility alarm notification system.

[11] The hold time is the duration of time from a fuel refill to the time when the relief valve opens up to relieve excess pressure built up due to heat leak into the tank. The hold time depends on the ambient temperature—the higher the ambient temperature, the lower the hold time. However, the hold time is even more dependent on the efficiency of the vacuum jacket surrounding the ***LNG*** tank. The less the vacuum the shorter the hold time.

LNG buses and other safety equipment which may be installed either on the buses or within the garage premises.[12] These features may include such actions as increasing the distance from the bus to the nearest electrical equipment, making the equipment and electrical systems of non-sparking solid state devices, lower voltage in the equipment, among other items. Where specific electrical classification requirements exist, as a part of the state or local codes, these requirements should be adhered to in the facility design. Also, the basic concepts of safety regulations which may not be directly applicable to an ***LNG*** garage facility should be considered.

NFPA 70 recognizes that not all facilities in which flammable liquids or flammable vapors may escape from their normally confined state need to be classified as a Class 1, Division 2 facility for electrical systems. This implies that under certain circumstances an electrical classification less stringent than Class 1, Division 2 can be used even where flammable liquids are stored or where flammable vapors can escape. The transit agency should discuss the level of electrical classification protection needed (for the electrical equipment in a bus storage facility) with its A&E consultants and/or the local authority having jurisdiction. All local codes, standards, and regulations should be followed.

2.3.3 Ventilation and Heating

In addition to normal building ventilation that is required for a parking facility, ***LNG*** bus storage facilities should be provided with a means to remove any ***natural gas*** vapors generated by the release and evaporation of ***LNG***. There are no specific standards for ventilation of ***LNG*** bus storage/parking facilities. It is, however, prudent to implement the NFPA 57 §3-2.4.3 requirements for indoor fueling facilities and the requirements of NFPA 88A.

NFPA 57 requires the provision of a forced air ventilation when ***natural gas*** concentration in excess of 20% of LFL is detected anywhere in the facility. If exhaust fans are used for this application, these fans should be NEC Class 1, Division 2 classified since they may operate in a gas rich environment. Makeup air supply should be provided by means of low-level ventilation and/or a direct opening to the outdoors.

Furthermore, considerations should be given to de-energizing supply fans if they supply air above the bus. Existing high-level exhaust fans should be examined for possible ignition sources and perhaps shut down or even their ventilation ability negated by means of "spill air dampers."

The number of exhaust fans and their location should be determined. The design should meet local building code requirements. Care should be taken to have effective air changing, eliminating

[12] The requirement to classify electrically the garage building to a high degree of classification may be in conflict with the practice of parking a bus that is not electrically classified inside the same garage. To enhance the safety in an ***LNG*** bus parking garage, the facility designer may consider a systems approach which could include the safety systems in the bus as well as in the buildings, the combination of which could result in a minimum ***risk*** operation. Methods described in Chapter 3 of this document can be utilized to minimize ***risk***.

stagnant air pockets and reducing ***natural gas*** residence times. It should be noted that the codes do not specify the location of exhaust fans. Because vapors generated by the evaporation of ***LNG*** are heavier than air, it is prudent to provide significantly higher rates of air flow at floor level to disperse the vapors. The transit agency should work closely with its A&E firm to establish the proper ventilation strategy.

Heating equipment should be examined for high surface temperatures. Exposed flames in gas plume travel paths or in the area of flammability zones should be eliminated.

2.3.4 Types of Construction

Existing parking facilities are built using one of the types of construction defined in NFPA 220. For an ***LNG*** bus parking facility, it would be prudent to use open type beams, trusses and purlins so as not to create pockets for flammable gas in space between beams.

2.3.5 Combustible Gas Detection Equipment

Combustible gas detection equipment should be provided in areas that will result in the quickest response time in detecting the vapors generated by the evaporation of released ***LNG***. In addition, installing gas sensors at locations where a potential exists for gas accumulation or entrapment will lead to significant improvement in safety. Typically, sensors are mounted at ceiling level to monitor gas. Considerations should be given to detecting gas concentrations in the exhaust duct and at lower levels (closer to the ground).

A gas monitoring system should be included with threshold level outputs interconnected to trigger alarms, electrical shutdowns, including, possibly, vehicle electrical systems. Fans, louvers, doors, etc., can be automatically controlled to dilute and disperse gas concentrations. Detection sensors and other parts of the system used should be those that are approved, evaluated, or listed by Underwriters Laboratories (UL), Factory Mutual (FM), Canadian Standards Association (CSA), U.S. Department of Labor, Mine Safety and Health Administration (MSHA), or an Occupational Safety and Health Administration (OSHA) licensed National Recognized Testing Laboratory (NRTL) for installation in methane and ***natural gas*** environments. Routine sensor calibration should be done from floor level, not exposing personnel to ***hazards*** such as lifts, ladders, or moving equipment.

It is noted that there are no U.S. national codes or standards which specify the locations or the density (numbers per unit area) of combustible gas detectors. The transit agency should therefore consult with an A&E firm, the detector manufacturer, and/or the local authority having jurisdiction to determine the number and location of detectors.

2.3.6 Emergency Systems

The accidental release of ***natural gas*** should be handled by ventilators, de-energizing of spark producing equipment or classification of electrical components. Therefore, it is important to maintain these systems in working condition even in the event of loss of electrical power or brown out. A backup power supply is desirable. However, it should be ensured that the backup power does not in itself create an ***ignition source*** due to switching of electrical devices.

It may be possible to utilize existing generators in the facility, if one is available. Discussion with a utility provider should be conducted to ascertain the appropriate method of maintaining the gas remediation and detection systems, under all conditions, especially in an emergency.

Attention is drawn to possible conflicts of a fire alarm system and a combustible gas detection system. Typically, when a fire alarm is activated, ventilation is interrupted and fire rated barriers are closed. Upon natural (combustible) gas detection, ventilation is increased and barriers are opened to stimulate air movement. One other conflict between fire and natural combustible gas detection systems is the energization of fire alarm bells throughout a facility. Since these bells may be spark producing, they may pose an ignition ***hazard***. The local authority having jurisdiction and the agency's insurance underwriters should be consulted to ascertain the priority level of alarms.

Audible alarms provided as a part of the emergency system should be in compliance with the requirements of the ADA Accessibility Guidelines (1991), Section 4.28.2, indicated below.

> ***4.28.2* Audible Alarms.*** *If provided, audible emergency alarms shall produce a sound that exceeds the prevailing equivalent sound level in the room or space by at least 15 dbA or exceeds any maximum sound level with a duration of 60 seconds by 5 dbA, whichever is louder. Sound levels for alarm signals shall not exceed 120 dbA.*

The visual alarm signal appliances have to comply with the requirements of Section 4.28.3 of the Accessibility Guidelines.

2.3.7 Safety Interlocks

Consideration should be given to incorporating the following features in electrical equipment designs:

- Permitting manual resetting of tripped circuits or equipment activated in an emergency.
- Providing audio and visual indications when a detection or other ***natural gas*** equipment is off-line for maintenance.
- Locating key activated interlocks at remote locations (such as next to facility fire alarm panels) for ventilation and reestablishing priority functions in case of a fire/gas emergency.
- Locating manual trip stations which provide similar activation of ventilation and electrical ***controls***.
- Interlocking emergency systems to a "on" default when problems are being encountered or maintenance is being performed on detection or other input notification systems.

2.3.8 Operations in a Storage Facility

A transit system should implement other (passive) safety practices in ***LNG*** bus parking garages as a part of routine operations. Associated with these practices should be the training of personnel—including bus operators—to understand the various safety issues and to inculcate a "safety first" attitude in day-to-day operations. These passive safety enhancement procedures should include but not be limited to:

1. Strictly enforcing a rule which requires ***LNG*** fueled buses to be parked only in the designated lanes within the garage. These lanes should be provided with gas concentration sensors, both ceiling mounted as well as in other identified areas. (It is assumed here that a garage may be used to park buses using a variety of other fuels, namely, diesel, gasoline, methanol, among others. If the garage is a dedicated ***LNG*** storage facility, designated parking is not relevant.)

2. Ensuring that no ***LNG*** bus which has sprung a fuel leak, however small the leak rate may be, is ever allowed to be brought into the garage nor allowed to be parked in the garage.

3. Strictly prohibiting smoking by anyone anywhere except in designated smoking areas.

4. Providing a portable hand-held ***natural gas*** concentration measuring instrument at a convenient and easily accessible location either within or very close to the storage facility. This instrument could be used to detect near ground level gas concentrations if anyone suspects a fuel leak from a bus parked in the garage. Any such detection should be followed by the implementation of an appropriate level of response. It should be noted that vapors emanating from the evaporation of ***LNG*** are odorless and hence cannot be detected by smell (which is possible in the case of gas leaking from a ***CNG*** powered bus).

5. Developing a proper written response plan for various types of ***LNG*** leak emergencies. These plans should include action items to respond to different size releases. The response plan should include evacuation plans for personnel within and nearby the garage and safe withdrawal of buses parked inside the garage, if a sizeable release has occurred. Additional requirements for an emergency plan are discussed in Section 2.7.

6. Limiting the time the vehicle is parked in the storage facility. This is because of the issues of handling the gas released due to ***LNG*** tank overpressure caused by heat leak.

7. Assuring that only minor maintenance is performed in the bus parking area. Dead engines and other assorted problems arising from parking a vehicle should be addressed minimally in the storage area. Major repairs should not be performed.

2.4 BUS MAINTENANCE FACILITY

A bus maintenance facility is generally a partial or fully enclosed building within which repairs and routine servicing of buses are performed. In many transit systems, this facility consists of one or more bays consisting of either a lift or a pit over which the bus to be serviced is parked. Some transit systems may use the same maintenance facility for servicing ***LNG*** and other fuel buses. The dedicated section of the facility is generally upgraded with the provision of gas sensors, alarms, and special equipment. Discussed below are special issues of design and operational practices of an ***LNG*** bus maintenance facility which should improve safety.

The definition of a repair facility can be found in NFPA 88B. Only buildings meeting those definitions (or use) are discussed in this section. Garages without physical barriers between parking and maintenance of vehicles (not for vehicle dead storage) are also within the purview of this section.

In general, all requirements for safety in a bus storage area (discussed in the previous section) should be assumed to be applicable to a bus maintenance facility. However, there are exceptions and somewhat more restrictive requirements in a maintenance facility because of the nature of work being performed in this facility and the (increased) potential for ***LNG*** release incidents to occur compared to that in a storage facility. **Therefore, the reader should review the requirements for the storage facility (Section 2.3 of this document) and assume that all of those design guidelines are a part of this Section also.** Only additional requirements for a maintenance facility are indicated in the subsections below.

2.4.1 Design Overview (Bus Garage)

All of the facility design philosophy indicated in Section 2.3.1 are made a part of this section by reference.

Because of the various types of repairs that are performed and the variety of tools used (including electrical) the potential for accidental release of ***LNG*** is present. Therefore, special designs need to be implemented to reduce the potential for ***LNG*** release as well as elimination of ignition sources in the maintenance area. This may be achieved by using only electrically classified equipment or using pneumatically operated tools. In addition, all of the gas detection and dispersal strategies discussed in earlier sections should be implemented. Also, special precautions need to be taken to ensure that any ***LNG*** spilled on the maintenance shop floor does not enter the sewer or water/oil drainage system. Applicable systems of NFPA 88B and EPA Regulations should be followed in the design of this system.

2.4.2 Electrical Equipment

In a maintenance facility there are both fixed and movable electrical machinery that may or may not be classified. These include fans, power tools, lights, radios, heaters, etc. A transit system should assess the potential for ignition from all electrical equipment used (or proposed to be used) in a maintenance facility and initiate appropriate design or use modifications to reduce or eliminate the ignition potential. The design changes may include:

- Electrically classifying the equipment according to the requirements of NFPA 70.
- Replacing electrical spark producing equipment and tools with air operated machinery.
- Avoiding the use of hot element electrical heaters.

If the maintenance facility has work pits, they should be provided with lights and electrical outlets which are certified Class 1, Division 2.

The design modifications should be discussed with the transit system's A&E firm, insurance carrier, and local fire department. It is necessary to comply with all regulations and local code requirements.

2.4.3 Ventilation and Heating

In addition to normal building ventilation that is required for a repair facility (NFPA 88B, OSHA Guidelines), ***LNG*** bus repair facilities should be provided with a means to remove ***natural gas*** from the facility and/or promote mixing of the air in the space above the vehicle to lower gas concentrations below LFL. Care should be exhibited in promoting mixing so as not to dilute higher than UFL concentrations back into the flammability ranges. Therefore, considerations to shutting down existing high-level supply fans should be explored. Consideration should be given to a design in which the roof mounted exhaust fans are automatically activated when concentrations over 20% LFL are sensed. These fans should be Class 1, Division 2 since they will operate in a gas rich environment. Makeup air should be provided by means of low-level ventilation and/or a direct opening to the outdoors. However, in cool climates makeup air could be heated or tempered to maintain comfortable conditions for personnel in the location.

Provisions should be made in the maintenance facility to exhaust to the outside any bus ***LNG*** tank vented gas. This can be achieved by providing a flexible hose that can be placed over the ***LNG*** tank vent line, the other end of the hose being connected to an explosion-proof exhaust fan.

Existing exhaust fans which either spark or are not classified as Division 2 may pose a potential gas ignition ***hazard***. Therefore, consideration should be given to replacing the sparking fans with non-sparking, Division 2 classified fans. If this is not feasible, a ***risk*** assessment should be performed, as outlined in Section 3 of this document and appropriate, acceptable, technical solutions should be developed.

All other requirements discussed in Section 2.3.3 of this document should be considered. In particular, it should be ensured that there are no hot surfaces (to which a gas pocket or ***natural gas*** plume may come in contact) with temperatures in excess of 700 K (800 °F).

2.4.4 Types of Construction

The requirements presented in Section 2.3.4 apply to the bus maintenance facility also. Specifically, the types of construction for large facilities housing vehicles discussed in NFPA 220 should be reviewed. As indicated before, it will be prudent to use open type beams, trusses, purlins, and other types of structures in facility design so as to prevent accumulation of ***natural gas*** and formation of flammable gas pockets.

2.4.5 Combustible Gas Detection

All of the requirements for a storage facility discussed in Section 2.3.5 should be construed to be applicable to a maintenance facility. In addition, where maintenance facilities have pits, consideration should be given to installing combustible gas sensors. Also, consideration should be given to providing gas sensors at levels close to the floor at strategic points in the maintenance facility.[13]

2.4.6 Emergency Systems

All of the requirements of Section 2.3.6 should be deemed to be applicable to this Section also.

2.4.7 Safety Interlocks

The requirements discussed in Section 2.3.7 should be assumed to be applicable to this Section. In addition, where there is a potential for ***LNG*** released to run to sewers or water/oil traps, proper designs have to be implemented to contain released ***LNG*** in impoundment areas. This may involve a small diked area (about 15 cm high or 6 inches) in the service bay.

Means should be provided to manually operate the maintenance bay doors and pull the bus away from the service bay, in case of a leak.

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[13] Vapors generated by the boiling of ***LNG*** on warm surfaces (ground, bus panels) are heavier than air. Mixing of these vapors without any external sources of heat results in a gas cloud that remains heavier than air. Hence, the gas cloud can linger at ground level for a long time.

2.4.8 Other (Passive) Safety Practices

The safety practices in Items 1 through 6 of Section 2.3.8 are applicable to operations and maintenance facilities. In addition, the following should be considered for implementation in a maintenance facility.

1. Procedures should be implemented to ensure that no part of the bus fuel system is impacted, either mechanically (i.e., impacts) or electrically, during the time an ***LNG*** bus is being serviced for non-LNG related reasons (e.g., for brake, steering, wheel, or other routine maintenance).

2. Consideration should be given to ***defueling*** a bus outside the maintenance facility when any part of the fuel system on a bus is known to have a leak.

3. Detailed instructions should be provided to the staff and ***fail-safe*** procedures implemented to prevent a bus which is leaking ***LNG*** (even at a small rate) from being moved inside the maintenance building. A leaking bus should be serviced outdoors.

4. Only mechanics, trained in servicing an ***LNG*** fuel system, should be allowed to perform maintenance on ***LNG*** fuel systems.

5. Adequate training and instruction should be provided to mechanics working on an ***LNG*** system, including information on proper procedures for tightening compression fittings, testing for vapor leaks, handling cryogenic lines, etc.

2.5 BUS FUEL SYSTEM

Part of the planning for the inclusion of LNG-powered buses into fleet operations entails examining the LNG-powered bus itself. This examination should include the on-board fuel delivery and storage system design, components and interconnections, and the on-board safety detection, location and suppression systems. Further, the adoption of some basic precautionary procedures prior to vehicle repair operations should be explored to enhance the safety of operating ***LNG*** buses within the existing fleet.

Figure 2-1 shows schematically the ***LNG*** fuel system in a transit bus. An ***LNG*** bus fuel system consists of a cryogenic, double walled ***LNG*** tank, a ***vaporizer*** to evaporate ***LNG*** into vapor (which is supplied to the engine), and a refueling pipe which has a receptacle at one end. The receptacle end is located on the side of the bus, and a connection to the ***LNG*** tank at the other end. A number of check valves and a pressure tank relief valve are part of the fuel system as also are the systems to measure tank temperature and pressure. An important part of the fuel system is the ***defueling*** connection (to the liquid side) of the tank to enable the removal of liquid out of the tank if a need arises. ***LNG*** is vaporized using the heat from the engine coolant which is circulated through the ***vaporizer***.

This section discusses a philosophy to be applied when exploring the design of the fuel storage and delivery system on a transit bus. System components, the use of on-board leak detection, location and suppression systems, and procedures that might be utilized during maintenance operations are also discussed. The proper selection of equipment, design parameters and preliminary maintenance procedures will offer the bus transit facility operational flexibility while ensuring a high degree of ***risk*** mitigation.

2.5.1 Fuel System Design Philosophy

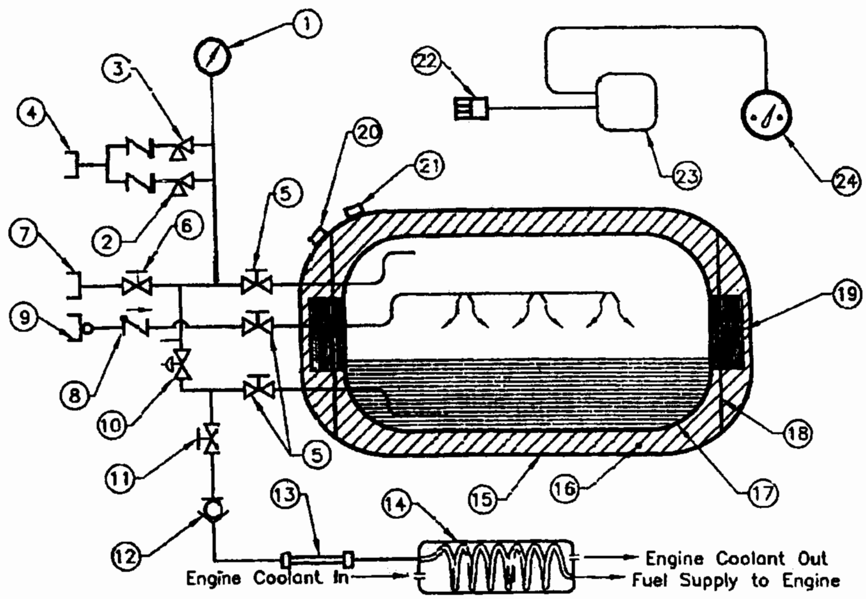
An ***LNG*** leak from a transit bus is a low probability event. However, the fuel system should be designed to minimize the quantity and duration of release to prevent potential ***hazards***.

The fuel system design philosophy should be to ensure that:

- the integrity of the fuel system during both normal operations and accident conditions is maintained;
- the relief valve pressure is set as high as possible consistent with the tank specifications;
- cryogenic liquid does not flow through the ***vaporizer*** to the engine intake (as a liquid) in the event the heating of the ***vaporizer*** is interrupted;
- appropriate interlocks are provided to prevent the bus from moving away when the refueling hose is connected; and
- fuel supply to the engine is shut-off and the ***LNG*** tank is isolated when a gas leak is detected.

The implementation of the above issues is discussed in the following subsections.

Figure 2-1
Schematic Representation of the LNG Fuel System on a Bus



LEGEND			
Item No.	**Description**	**Item No.**	**Description**
1	Pressure gauge	13	Flexible hose
2	Primary relief valve	14	Vaporizer
3	Secondary relief valve	15	Outer tank
4	Vapor line connector	16	Insulation
5	Isolation valves	17	Inner tank
6	Isolation valve	18	Support System
7	Vapor line connector	19	Bumper
8	Fill check valve	20	Vacuum port
9	Refueling connector	21	Instrumentation port
10	Economizer regulator	22	Sensor
11	Isolation valve	23	Electronic signal converter
12	Vertical check valve	24	Level gauge

Source: PTL, 1996

2.5.2 Bus Vendor/Manufacturer Design Discussions

Prior to finalizing the bus design/fabrication, discussions should be held, where possible, with the bus manufacturer to:

- Explore several alternative configurations for fuel components and their effectiveness and choose the one which presents the minimum ***risk*** (potential ***risk*** may be calculated using the methodology outlined in Section 3).

- Insure (high) component reliability and safety, especially during maintenance operations.

- Perform an analysis to determine the potential for ***LNG*** or vapor releases from components (either during normal operations or during accident conditions), quantity of LNG/vapor that may be released, and actions that can be initiated to reduce or eliminate such releases.

Items to be explored should include ***LNG*** tank, mountings, ***vaporizer***, valves, check valves and pressure gauges, fuel lines, manifolds, etc. The use of redundant critical components to ensure bus operation during severe operating conditions should also be considered.

In addition, the inclusion of on-board combustible gas detectors, fire suppression systems and bus locating systems that can be integrated into facility operations should be explored with the bus fabricator. This section includes a discussion of some of these available systems in more detail.

2.5.3 Fuel Delivery System Design Checklist

Some of the items for consideration when exploring the design of the fuel delivery system on a transit bus are:

- Providing redundancy for fuel supply components that are critical to engine operation and which may be susceptible to high failure rates.

- Including several manually operated quarter-turn valves for isolation of equipment and long runs of tubing.

- Selecting stainless steel and cryogenically rated tubing for pressure and abrasion resistance.

- Placing pressure gauges in critical places so that they can be used effectively during maintenance operations.

- Incorporating in the design several flow check valves for added isolation and flow control.

- Selecting and providing electrically operated solenoid valves in order to isolate the system when the bus is not operational.

- Installing a battery disconnect switch in the engine compartment.

Again, the goal is to carefully select and place equipment and components in a configuration that reduces the ***hazard*** potential and reduces the probability of occurrence of an ***LNG*** leak event.

2.5.4 Fuel Storage System Design Checklist

Some of the items for consideration when exploring the design of the ***fuel storage system*** on an ***LNG*** transit bus are:

- Effectiveness and features of the ***LNG*** tank mount to withstand road vibrations as well as minimizing heat leak into the tank.

- The integrity of the connection between the tank and the pipes penetrating the tank (liquid fill, vapor relief, ***defueling***, etc.). Because the pipes penetrate the vacuum space, the penetrations should be designed to be air leak proof.

- Selection and strategic placement of electrically operated solenoid valves in order to isolate each tank and other parts of the fuel system when the bus is not operational.

- Provision of manually operated quarter-turn valves close to the tank on the liquid extraction line and refueling line to ensure tank isolation in case of an emergency.

- Selection of stainless steel cryogenic rated tubing for pressure and abrasion resistance.

- Effective placement of pressure gauges to read both the tank internal pressure as well as the level of vacuum in the annular space between inner and outer tanks.

- Effective placement of flow check valves for added isolation and flow control.

- Placement of an on-board ***fuel storage system defueling*** connection. Its use will be discussed later in this section.

- Providing protection to critical fuel components against impact from dropped tools, road debris, and other accidental damage.

The goal is to carefully select and place equipment and components in a configuration that precludes the ***hazard*** potential caused by a large leak event.

2.5.5 Fuel Delivery and Storage System Operation

The following safe operating practices related to fuel delivery and storage system operations are to be considered when the system is designed.

- **Bus Parked and Engine Off.** When the bus ignition is turned off, all electrically operated solenoid valves should be in a closed position. Fuel flow should cease and the *LNG* tank should be isolated.

- **Bus Fueling.** A bus engine ignition cutoff switch should be provided on the fuel refill door. The electrical connections should be such that when the fueling port door is open, engine ignition is deactivated. This design will ensure that the bus cannot be driven away when the refueling hose is connected to the fuel receptacle.

- **Bus Maintenance.** When it is necessary to bring the bus inside a facility for maintenance work, and the ignition is shut-off all electrically operated solenoid valves should be closed automatically. This will limit the volume of ***LNG*** or ***natural gas*** in the fuel delivery system that can leak out if there is a break.

2.5.6 Gas Leak Detection and Fire Suppression Systems

There are commercially available systems for on-board fire safety detection and suppression for installation on a bus. These systems can detect the leakage of ***natural gas*** or the heat rise from an on-board fire and will suppress that fire with a dry chemical extinguisher. These systems are available for use in the bus engine compartment or in the fuel storage area or both. Also, on-board locating and alarm systems are commercially available. These systems will annunciate an on-board leak or fire through an alarm (bell or siren) and transmit a signal to a base station for early detection. The fire detection and suppression systems can be designed to be active while the bus is in operation or when it is parked. The facility operator should explore the inclusion and use of these devices on the buses or in conjunction with the other safety systems installed within their facilities.

In one transit system[14] ***LNG*** buses are equipped with a methane detection system which alerts the bus operator if gas concentrations above set levels are detected under the bus chassis or inside the bus. At 15% of LFL, a dash light is illuminated and a faint alarm is sounded. At 30% of LFL, the ***LNG*** fuel pump is shut-off and the alarm is locked on. It can only be reset by a maintenance action. At 45% LFL, the operator is instructed to take the bus out of service. If the bus is parked and not in service when this level of methane concentration is detected, the alarm triggers the vehicle horn to annunciate the presence of a gas leak problem.

An ***LNG*** bus can also be equipped with a dry chemical automatic fire suppression system. This system utilizes heat sensor (bulbs) in critical areas such as ***LNG fuel tank***, ***vaporizer***, and engine compartment, and when activated, shuts the bus engine off. Restart of engine requires a maintenance action. In addition to automatic operation, the system can be activated manually by a palm valve in the driver area. The dry chemical is stored in two bottles containing approximately 11 kg (25 lbs) each.

2.5.7 Precautionary Procedures Prior to Maintenance

The following is a list of some on-board safety precautions that should be considered for incorporation into maintenance procedures:

- When an LNG-powered bus is brought into a maintenance facility for repair, the battery disconnect switch, if available, should be set to the "off" position. The quarter-turn fuel delivery system manual shut-off valve that is closest to the engine and the one on the ***LNG*** tank delivery line should be closed. This should be effected prior to initiating any work on the bus.

- For major repairs (over four hours of duration), each available quarter-turn shut-off valve on the fuel delivery system should be manually closed.

- If repairs to the bus include "hot work" or tools that spark, i.e., welding or grinding, or require work on the ***fuel storage system***, then the fuel in the ***fuel storage system*** and throughout the fuel delivery system should be removed. ***Defueling*** procedures are discussed in the next section.

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[14]Houston Metro

CAUTION

If the fuel delivery or storage system has failed on the bus and either LNG or natural gas is escaping, the leaking system should be isolated by manually closing adjoining valves. A BUS LEAKING FUEL SHOULD NOT BE BROUGHT INTO AN ENCLOSED MAINTENANCE FACILITY. Only when the failed system has been isolated and the leak stopped should the bus be brought indoors to effect permanent repairs.

2.5.8 *Bus Defueling*

Circumstances may arise which necessitate the removal of ***LNG*** fuel from a bus before it can be serviced and operated again. Examples of these situations are: (i) removal or replacement of the cryogenic pump; (ii) leak of liquid from lines connected to the liquid side of the tank; (iii) an imminent fire scenario; (iv) damage to the ***LNG*** tank; (v) loss of vacuum in the jacket; and (vi) when the bus is likely to be inside the maintenance shop for more than 48 hours. In general, ***LNG defueling*** involves pumping the liquid in the bus tank under a gas pressure into another cryogenic ***container***. Where feasible the ***LNG*** removed can be pumped back into the facility's ***LNG*** storage tank. Described below are some of the safety and other system considerations involved in the ***defueling*** process.

2.5.8.1 Precautions

The most important factors to be considered in the ***defueling*** process are:

- the operation should be performed with a high degree of care and safety consciousness; and
- no ***LNG*** or methane vapor should be released to the atmosphere.

Other precautions that should be observed during the process of ***defueling LNG*** include the following:

CAUTION

1. **Defueling should be performed outdoors, away from any existing buildings or sources of ignition.**

2. **There should be no smoking, open flames or other sources of ignition in the vicinity during the defueling of LNG from a bus. When natural gas may be intentionally vented into the atmosphere, it is of paramount importance to properly and adequately electrically ground any tubing or storage system.**

3. **Controlled defueling should be performed only if a proper connection is provided on to the bus fuel storage system.**

2.5.8.2 Defueling System Components

It should be noted that in most cases pressure in the on-board ***LNG*** tank will be higher than in the facility storage tank. Therefore, to pump the ***LNG*** from the bus tank to the storage tank no pump is needed. However, as the liquid level drops in the bus tank during the downloading, the pressure also will decrease. In order to maintain the bus tank-to-storage tank flow a non-combustible dry pressurized gas (such as nitrogen) may be used. Dry nitrogen pressure should be at least 150 kPa (about 20 psig) higher than the storage tank pressure in order to ensure a unidirectional ***LNG*** flow from the bus tank to the storage tank.

The general system and component requirements for performing ***defueling*** are:

1. Liquid nitrogen cylinders with regulators.

2. ***Defueling*** hose that has a cryogenic duty rating and has proper connectors at both ends.

3. Provision of a port on the bus (fuel system) to which the nitrogen supply can be connected.

4. Provision of check valves on the transfer lines between the bus and the storage tank (to prevent back flow into the vehicle) and manual shut-off valves.

5. Means to identify that all liquid from the bus tank has been removed. (Many times this can be discerned by the change in the sound pitch emanating from the transfer hose.)

2.5.9 Scheduled Defueling Sequence

The following illustrates the general procedure and sequence of steps in an ***LNG defueling*** procedure.

1. The vehicle should be parked for ***defueling*** near the "fuel receipt connector." This connector is the same that the ***LNG*** delivery vendor uses to fill the storage tank from an ***LNG*** transport.

2. All of the safety procedures that are followed during storage tank filling (or fuel transfer) process should be followed.

3. The ***defueling*** hose should be connected to the ***defueling*** port on the bus and the other side should be connected to the "fuel receipt connector" of the storage tank.

4. The nitrogen cylinder should be connected using the properly pressure-rated hose to the nitrogen access port on the vehicle.

5. The quarter turn valves on the liquid transfer line on the vehicle should be opened followed by the opening of quarter turn valve downstream of the fuel receipt connector on the storage tank side.

6. The nitrogen pressure should be raised to about 150 kPa (~20 psig) above vehicle tank pressure by appropriately adjusting the regulator on the liquid nitrogen bottle.

7. The quarter turn valves on the vehicle nitrogen port access and at the nitrogen source end should be open.

8. The *LNG* starts flowing from the vehicle tank to the facility storage tank. The tank pressures should be continuously monitored and the nitrogen pressure should be appropriately adjusted to maintain a 150 kPa (~20 psi) differential between vehicle-to-storage tank pressure.

9. When the liquid transfer is complete, the shut-down process should be performed by reversing the sequence of steps indicated above.

Completion of liquid transfer can be determined by a change in sound of flow and a change in the vibration of defueling hose.

Although all of the liquid has been removed from the vehicle, there will be gaseous methane in the tank. It is necessary to remove this gas to ensure that the fuel tank is safe to service. This can be performed by redirecting the gas emanating from the vehicle tank to the vent stack at the storage tank by appropriately operating the gas vent valve on the storage tank plumbing.

2.5.9.1 Reduction of On-Board Gas Pressure

There are instances when the gas pressure inside the tank pressure needs to be reduced without removing the liquid. These circumstances may include the need to work on specific fuel system components or safety concerns of a system with a high tank pressure and therefore of a relief valve operation when the vehicle is inside a shop. In these cases, the *LNG* tank pressure should be reduced to a safe level. The following procedure should be employed to achieve a safe *LNG* tank pressure.

1. Position the vehicle at the facility ***LNG*** fueling station.

2. Follow the facility safety procedures as if the vehicle was ready to be refueled.

3. Connect the vent nozzle to the vent receptacle on the vehicle for Parker type connections. (For MOOG, connect the nozzle assembly to the receptacle.)

4. Open the bypass manifold quarter turn valve.

5. (Parker Only) Open the vent nozzle handle.

6. Slowly open the vehicle vent quarter turn valve to the fully open position.

   Note that this will allow venting of vehicle tank only to the pressure level of the storage tank.

7. Monitor the tank pressure gauge.

8. Once vehicle tank pressure is down to desired pressure, close the vent quarter turn valve on the vehicle and disconnect the nozzle.

> ***In some LNG fueling stations the vent gas downloaded will exit out of the station's atmospheric vent stack rather than into the storage tank. Also, in some stations, one additional valve must be operated which is the station vent quarter turn valve to let the escaping gas into the atmosphere.***

2.6 PERSONNEL TRAINING

The safe operation of any ***LNG*** bus transit facility will depend very strongly on the level of training given to various personnel throughout the facility as well as on the commitment to safety from management. Safety consciousness can only be achieved by providing continuous training for all personnel (including management). Training programs should be developed to include all personnel who will be directly or indirectly involved in the maintenance, operation, fueling or storage of ***LNG*** buses.

In addition, training should be provided to personnel in emergency services (fire department, local ambulance and rescue) so that they are better prepared to respond to an ***LNG*** release emergency.

The following individuals (at a minimum) should be provided with formalized training.

- Fuelers
- Bus Operators
- Mechanics
- Supervisors
- Management Staff
- Other Building Occupants
- Local Emergency Response Personnel

The different topics that should be covered in a training program will depend on the skill level and nature of responsibility of the personnel being training. Table 2-4 shows a matrix of types/topics of training and the category of personnel. The information in this matrix should be used as a guide to determine the minimum training to be provided. In some cases, the type of training to be provided for ***LNG*** use will be similar to that which is required for other fuels.

All personnel and local fire department response personnel should be given "General Training" covering such topics as the physical properties of ***LNG***, density, temperature of liquid, vapor characteristics, fire ***hazards*** and skin burn ***hazards***, etc. (The information provided in Section 2.1 of this document should be included in this general training.) In addition, all transit personnel who are associated with bus operations should be informed about the safe handling of ***LNG*** (and other fuels), emergency procedures in case of ***LNG*** release, first aid response to skin exposure/contact with ***LNG***, etc. Other specific training should include the following.

2.6.1 *Drivers' Training*

The drivers should be given training to educate them about ***LNG*** and the differences in operation of ***LNG*** buses compared to diesel buses. Special emphasis should be placed on passenger safety. The drivers should be trained specifically in the correct response to indications of a fuel leak by methane sensors and their response to vehicle fires.

Table 2-4
Training Topics for Various Personnel

Training Topics	Fuelers/ Mechanics	Building Occupants	Bus Operators	Emergency Response Personnel	Local Groups	Manage-ment	Utilities
Physical/Chemical Properties of the Fuel	✓	✓	✓	✓		✓	✓
Safe Handling/Fueling Procedures	✓		✓				
Emergency Notification Procedures	✓	✓	✓			✓	
Emergency Evacuation Procedures	✓	✓	✓	✓	✓	✓	
Fire Detection/Suppression Features	✓	✓	✓	✓		✓	✓
Vehicle/Facility Safety Features	✓		✓	✓		✓	
Safe Repair/Maintenance Procedures	✓					✓	
Licenses/Permits Required/Certification	†		†			‡	‡
Fire Prevention	✓	✓	✓			✓	
Emergency Preparedness Drills	✓		✓	✓	✓	✓	✓

† If Applicable ‡ As Required

2.6.2 Fuelers' Training

Fuelers should be given specific operational procedures information about ***LNG*** refueling. All refueling procedures should be explained to the fuelers by the dispenser manufacturer and the fuelers should be allowed to practice connecting and disconnecting the equipment until they feel comfortable with it. The fuelers should be trained to wear the special gloves, apron, leggings, and face shield which should be provided as safety equipment to protect against exposure to liquid fuel or cold equipment. All safety equipment required for refueling should be demonstrated and the need for always using the safety equipment should be emphasized. It is necessary for an engineer representing the fueling station designer/constructor to be present during the first few days of normal operations to confirm and reinforce the use of proper refueling procedures. This will help to build the confidence of the fuelers and add depth to their training.

2.6.3 Mechanics' Training

Mechanics should receive training from the engine manufacturer on general tuneups of the engines. Specific safety procedures for working with lines that could contain cryogenic fluid or high pressure gas should be a part of this training. In addition, all mechanics who are expected to work on ***LNG*** powered buses should be given a guided tour of the vehicle fuel system. This tour will give them a first hand look at where each component is, and a better understanding of the function of each component. Mechanics should also be trained in maintaining, calibrating, and diagnosing problems related to the on-board methane detection system and fire suppression system. Mechanics also should be made familiar with refueling procedures.

2.6.4 Other Training Issues

Training in all areas identified in Table 2-4 can be accomplished in a variety of ways. In-house training is probably the most cost-effective way to provide training to the employees, provided a training department exists within the organization. If proper in-house technical information is not available, Train-the-Trainer courses are available from government agencies and private training companies. The FTA offers one such course entitled "Instructor's Course in Alternative Fuel Safety" at the Transportation Safety Institute (TSI). This type of training can also be used to reinforce in-house trainers' technical training material so that it can be passed on to the transit agency employees.

Insurance companies and utility companies are also a source for training material. These training courses are generally given at specific locations but can also be brought to a transit agency.

Recordkeeping is an important part of any training program. The type of training provided, the date, and number of hours taken, are all critical data should there be an accident. Copies of training records should be included in the employees' personnel files.

Maintenance records of equipment failures become very important when trying to isolate and identify equipment problems. Every failure, no matter how small in nature, should be recorded and, if possible, investigated to determine why the failure occurred. If needed, the manufacturer should be called in to offer technical assistance.

Local fire department, police, and emergency medical service personnel should also receive training on the location of all safety ***controls***, the ***hazards*** associated with ***LNG***, and any special information on systems installed.

Fire drills should be conducted on a regular basis and records kept and made available for inspection by fire department and/or safety personnel. Deficiencies in the evacuation of a building or any problems with alarm/detection equipment should be documented and forwarded to the appropriate person for corrective action. OSHA regulations require that fire drills be conducted on a regular basis.

Fire alarm systems as well as fire suppression systems installed in a facility as well as on buses should be inspected on a regular basis and conform to manufacturer's requirements and/or local codes, if any. In addition to the regular inspections, periodic testing of this equipment may also be required. NFPA standards should be consulted to determine exact testing procedures and inspection intervals. Records of these inspections and tests should be kept on the premises. Additional information is included in Section 2.2.6 "Maintenance of Safety Equipment" of this document.

Fire prevention should be practiced whether or not ***LNG*** buses are used. Good housekeeping and the proper storage of flammable and combustible materials are essential in order to provide employees with a safe workplace. When ***LNG*** buses are being utilized, precautions should be taken to ensure that ignition sources are kept away from potential gas pockets. Strict enforcement of "no smoking" policies, adequate ventilation, the use of non-sparking tools, and the use of personal protective and safety equipment will go a long way toward eliminating potential problems.

Some jurisdictions may require special licenses or permits from the fire department to operate ***LNG*** buses. The transit agency should check local regulations to see whether or not these are required. In addition, they may also require obtaining necessary fire department permits or licenses to operate the fueling station as well as the bulk storage of ***LNG*** and/or ***LNG*** buses. Other permits may be the responsibility of the local utility supplying the fueling station. In all cases, proper licenses and permits should be obtained prior to operation.

2.7 EMERGENCY PREPAREDNESS

The establishment of an Emergency Response Action Plan constitutes an important part of a facility's safety management in a facility handling/storing/or dispensing a hazardous/flammable material such as ***LNG***. The Emergency Response Action Plan should be a **written document** which addresses the following issues.

1. Identification of emergencies (detection and classification).

2. Action times required, their implementation sequence and the time duration within which to initiate different actions.

3. Notification procedures and a notification list which should include both internal (i.e., transit agency) and external (fire service, ambulance, police, et al.) contacts.

4. Evacuation procedures and required training to implement such procedures.

5. Location and type of safety systems (both in the facility and on the bus).

6. Event suppression or management actions which should include personnel rescue, fire suppression strategies, evacuation of personnel, and protection of property as yet unaffected.

OSHA's Personnel Protection regulations require the employer to have an "Employee Emergency and Fire Prevention Plan" (29 CFR §1910.38). Specifically, 29 CFR §1910.38 requires the inclusion of the following items, as a minimum, in the plan:

OSHA

29 CFR §1910.38 Employee Emergency and Fire Prevention Plan

(i) *Emergency escape procedures and emergency escape route assignments;*

(ii) *Procedures to be followed by employees who remain to operate critical plant operations before they evacuate;*

(iii) *Procedures to account for all employees after emergency evacuation has been completed;*

(iv) *Rescue and medical duties for those employees who are to perform them;*

(v) *The preferred means of reporting fires and other emergencies; and*

(vi) *Names or regular job titles of persons or departments who can be contacted for further information or explanation of duties under the plan.*

The transit system should comply with the provisions of OSHA regulations and incorporate these requirements in its ***system safety*** plan.

Because of the potential impacts of a ***LNG*** release and ignition incident, it is important that the transit agency work closely with the local emergency response agency to develop a joint notification and action implementation plan.

Emergency preparedness drills involving the transit agency, fire department, emergency medical services and police should be conducted to test the effectiveness of the emergency action plan. This will help in minimizing unnecessary damage by familiarizing response personnel with the safety equipment installed. In areas where the transit system operates in more than one jurisdiction, drills should be rotated so that all jurisdictions have a chance to participate. Emergency plans should clearly identify what agency is in charge of the incident prior to an actual emergency in order to eliminate unnecessary delays.

These emergency exercises should be followed up with a critique. If problems are identified, additional training may be needed or the emergency action plan may need to be revised.

Transit employees should be made familiar with their agency's emergency action plan so they can implement it as soon as an alarm is sounded. This may include manning fire command stations, removing buses from other parts of the facility, or helping in the evacuation of the facility.

Depending on the location of the ***LNG*** facility, local civic groups, school boards, and local businesses should be made aware of any emergency action plans which could affect them in a major gas release incident.

In addition to providing training to the fire, police, and emergency medical services, the local gas company should be included in emergency preparedness.

Chapter 3
Alternative Fuel Facility System Safety Process

3.1 SAFETY REQUIREMENTS

The purpose of this section is to assist transit agencies in implementing a program to identify and resolve potential safety issues that may occur over the lifetime of the system. Such a program will assist in the development of a proactive safety assessment that allows for the identification and resolution of potential safety issues during the planning, design, construction, and operation of the transit system. This section identifies the important elements of a safety/***hazard*** assessment technique, by which a transit authority can conduct a ***risk*** assessment to address design issues when standards/codes do not provide the necessary definitive guidance or when a transit authority wishes to consider alternative designs.

A ***system safety*** program, discussed in Section 3.2, should be instituted during the system planning/design phase and continue throughout the system construction, renovation, operation and disposition of a facility used for the maintenance, fueling and/or storage of transit vehicles fueled with alternative fuels. The ***system safety*** program should emphasize the prevention of accidents by identifying and resolving ***hazards*** in a systematic manner in accordance with the Hazard Resolution Process elaborated in Section 3.3.4.

3.2 SYSTEM SAFETY PROGRAM

A ***system safety*** program should be implemented to identify and resolve ***hazards***. The transit authority should provide for the development of a System Safety Program Plan (SSPP) to assist in implementing and documenting that program. The SSPP should identify the responsibilities of all parties for implementing a ***system safety*** program.

The SSPP should:

- Have as its objective, to provide for the safety of passengers, employees, the public, and equipment.
- Encompass all system elements and organizations within the transit system.

- Identify the safety roles and responsibilities of all organizational elements, and require accountability.

- Designate one individual with the responsibility for the safety of the system who has clearly defined roles and responsibilities established through a written policy.

- Establish a safety program that contains a ***hazard*** resolution process including the procedures necessary to identify and resolve ***hazards*** throughout the system life cycle.

- Ensure transit authority management's commitment and approval, in the form of a signed policy, for allocation of resources required to maintain a high level of safety.

The individual identified to carry out the safety program should clearly have the authority to insure its implementation and should report directly to top management.

The SSPP should be developed during the planning/design phase of the alternative fuel transit facility and maintained current throughout the facility system's life cycle. The SSPP should be prepared in general accordance with the requirements of MIL-STD-882C, Task 102 or equivalent. The SSPP should, as a minimum, identify the scope of the ***system safety*** program activities including those discussed previously.

3.3 HAZARD IDENTIFICATION AND RESOLUTION PROCESS

A ***hazard*** analysis should be performed on all facility modification and new construction projects. This analysis should be initiated by defining the physical and functional characteristics of the alternative fuel vehicle and facility system to be analyzed. These characteristics should be presented in terms of the people, procedures, facilities, and equipment which are integrated to perform a specific operational task or function within a specified environment.

3.3.1 System Definition

The first step in the ***hazard*** resolution process is to define the physical and functional characteristics of the system to be analyzed. These characteristics are presented in terms of the major elements which make up the system: equipment; procedures; people; and environment. A knowledge and understanding of how the individual system elements interface with each other is essential to the ***hazard*** identification effort.

3.3.2 Hazard Identification

The second step in the ***hazard*** resolution process involves the identification of ***hazards*** and the determination of their causes.

There are four basic methods of ***hazard*** identification that may be employed to identify ***hazards***. These methods are:

- data from previous accidents (case studies) or operating experience;
- scenario development and judgement of knowledgeable individuals;
- generic ***hazard*** checklists; and
- formal ***hazard*** analysis techniques.

When identifying the safety ***hazards*** present in a system, a major concern is that only a portion of the total number of system ***hazards*** has been identified. Therefore, every effort should be made to identify and catalog the whole universe of potential ***hazards***.

There are several ***hazard*** analysis techniques that should be considered to assist in the evaluation of potential ***hazards*** and to document their resolution. These techniques include a Preliminary Hazard Analysis (PHA), Subsystem Hazard Analysis (SSHA), System Hazard Analysis (SHA) and/or Operational and Support Hazard Analysis (O&SHA). These analyses should be conducted in general accordance with MIL-STD-882C, Tasks 202 (PHA), 204 (SSHA), 205 (SHA) and 206 (O&SHA), or equivalent, respectively.

3.3.3 Hazard Assessment

The third step in the ***hazard*** resolution process is to assess the identified ***hazards*** in terms of the severity or consequence of the ***hazard*** and the probability of occurrence of each type of ***hazard***. All ***hazards*** that are identified should be assessed in terms of the severity or consequence of the ***hazard*** and the probability of occurrence. This should be accomplished in general conformity with the criteria outline in MIL-STD-882C, Paragraphs 4.5 and 4.6 or equivalent.

3.3.4 Hazard Resolution

After the ***hazard*** assessment is completed, ***hazards*** can be resolved by deciding to either assume the ***risk*** associated with the ***hazard*** or to eliminate or control the ***hazard***. The ***hazard*** reduction precedence is as follows:

- design to eliminate or control the ***hazard***;
- add safety devices;
- provide warning devices;
- institute special procedures and training;

- accept the ***hazard***; and
- eliminate the use of the system/subsystem/equipment that creates an unacceptable ***hazard***.

Various means can be employed in reducing the ***risk*** to a level acceptable to management. Resolution strategies or countermeasures in order of preference are:

Design to Eliminate Hazards. This strategy generally applies to acquisition of new equipment or expansion of existing systems; however, it can also be applied to any change in equipment or individual subsystems. In some cases ***hazards*** are inherent and cannot be eliminated completely through design.

Design for Minimum Hazards. A major safety goal during the system design process is to include safety features that are ***fail-safe*** or have capabilities to handle contingencies through redundancies of critical elements. Complex features that could increase the likelihood of ***hazard*** occurrence should be avoided. Changes may be made to an existing design to control the known ***hazard***.

Safety Devices. Known ***hazards*** which cannot be eliminated or minimized through design may be controlled through the use of appropriate safety devices. This could result in the ***hazards*** being reduced to an acceptable ***risk*** level. Safety devices may be a part of the system, subsystem, or equipment.

Warning Devices. Where it is not possible to preclude the existence or occurrence of an identified ***hazard***, visual or audible warning devices may be employed for the timely detection of conditions that precede the actual occurrence of the ***hazard***. Warning signals and their application should be designed to minimize the likelihood of false alarms that could lead to the creation of secondary hazardous conditions.

Procedures and Training. Where it is not possible to eliminate or control a ***hazard*** using one of the aforementioned methods, safe procedures and/or emergency procedures should be developed and formally implemented. These procedures should be standardized and used in all test, operational, and maintenance activities. Personnel should receive training in order to carry out these procedures.

Hazard Acceptance/System Disposal. Where it is not possible to reduce a ***hazard*** by any means, a decision must be made to either accept the ***hazard*** or dispose of the system.

Risk assessment estimates (Tables 3-1, 3-2, and 3-3) should be used as the basis in the decision-making process to determine whether individual facility, system or subsystem ***hazards*** should be eliminated, mitigated, or accepted. ***Hazards*** should be resolved through a design process that emphasizes the elimination of the ***hazard***.

Table 3-1
Risk Assessment

Frequency	*Hazard* Category			
	I–Catastrophic	II–Critical	III–Marginal	IV–Negligible
A–Frequent	**IA**	**IIA**	**IIIA**	**IVA**
B–Probable	**IB**	**IIB**	**IIIB**	**IVB**
C–Occasional	**IC**	**IIC**	**IIIC**	**IVC**
D–Remote	**ID**	**IID**	**IIID**	**IVD**
E–Improbable	**IE**	**IIE**	**IIIE**	**IVE**

(light shading)	IA, IIA, IIIA, IB, IIB, IC	Unacceptable
(crosshatch)	IIIB, IIC, ID	Undesirable (allowable with agreement from Authority having jurisdiction)
(blank)	IVA, IVB, IIIC, IID, IIID, IE, IIE	Acceptable with notification to the Authority having jurisdiction
(diagonal hatching)	IVC, IVD, IIIE, IVE	Acceptable

Table 3-2
Frequency Categories

Frequency	Definition of Term
A–Frequent	***MTBE*** is less than 1,000 operating hours
B–Probable	***MTBE*** is equal or greater than 1,000 operating hours and less than 100,000 operating hours
C–Occasional	***MTBE*** is equal or greater than 100,000 operating hours and less than 1,000,000 operating hours
D–Remote	***MTBE*** is equal or greater than 1,000,000 operating hours and less than 100,000,000 operating hours
E–Improbable	***MTBE*** is greater than 100,000,000 operating hours

Table 3-3
Hazard Categories

Hazard	Definition of Term
I–Catastrophic	Death, system loss, or severe environmental damage
II–Critical	Severe injury, severe occupational illness, major system or environmental damage
III–Marginal	Minor injury, minor occupational illness, or minor system or environmental damage
IV–Negligible	Less than minor injury, occupational illness, or less than minor system or environmental damage

3.3.5 *Follow-up*

The last step in the ***hazard*** resolution process is follow-up. It is necessary to monitor the effectiveness of recommended countermeasures and ensure that new ***hazards*** are not introduced as a result. In addition, whenever changes are made to any of the system elements (equipment, procedures, people, and/or environment), a ***hazard*** analysis should be conducted to identify and resolve any new ***hazards***.

This process should include full documentation of the ***hazard*** resolution activities. The effectiveness of the countermeasures should be monitored to determine that no new ***hazard***s are introduced. In addition, whenever substantive changes are made to the system, analyses should be conducted to identify and resolve any new ***hazard***s.

3.4 SAFETY PRINCIPLES

The following safety principles should be observed in the transit system operating alternative fuel vehicles (See Tables 3-1, 3-2, and 3-3 for the definition of undesirable and unacceptable ***hazards***):

1. When the system is operating normally there should be no unacceptable or undesirable ***hazard*** conditions.

2. The system design should require positive actions to be taken in a prescribed manner to either begin system operation or continue system operation.

3. The safety of the system in the normal operating mode should not depend on the correctness of actions or procedures used by operating personnel.

4. There should be no single point failures in the system that can result in an unacceptable or undesirable ***hazard*** condition.

5. If one failure combined with a second failure can cause an unacceptable or undesirable ***hazard*** condition, the first failure should be detected and the system shall achieve a known ***safe state*** before the second failure can occur.

6. Software faults should not cause an unacceptable or undesirable ***hazard*** condition.

7. Unacceptable ***hazards*** should be eliminated by design.

8. Maintenance activities required to preserve specified ***risk*** levels (Table 3-1) involve the elimination of unacceptable or undesirable ***hazard*** conditions during maintenance. These should be prescribed to the individual responsible for ***system safety*** during the design

phase. These maintenance activities should be minimized in both the frequency and in the complexity of their implementation. The personnel qualifications required to adequately implement these activities should also be identified.

3.5 VERIFICATION AND VALIDATION

The design and implementation of all ***safety critical*** hardware and software elements of the system, as identified in the ***hazard*** resolution process, should be subjected to verification and validation. The objective of this verification and validation activity should be to verify that all ***safety critical*** elements have been designed and implemented to achieve safe operation and to verify the level of safety achieved.

The verification and validation process should include:

1. The identification of all factors upon which the assurance of safety depends. Such factors should be directly associated with the design concept used.

2. The identification of all ***safety critical*** functions performed by the system.

3. Analyses demonstrating that all dependent factors are satisfied and that each ***safety critical*** function is implemented in accordance with safety principles. Each facility used for storing, maintaining and/or fueling alternative fuel vehicles should, in addition to the above, exhibit a calculated Mean Time Between Hazardous Events ***(MTBHE)*** of 100 million system operating hours or greater. ***System safety*** documentation should support this calculation and substantiate the methodology used to arrive at the result.

Glossary

Compressed Natural Gas (CNG) This is defined as natural gas above the gas main supply pressure. The gas main supply pressure can be as low as 5 pounds per square inch and as high as 800 pounds per square inch or more.

Container A pressure vessel, generally of cylindrical shape, used to store the fuel.

Container Appurtenances Items connected to container openings needed to make a container a gastight entity. These include, but are not limited to, pressure relief devices; shut-off, backflow check, excess flow check, and internal valves; liquid level gauges; pressure gauges; and plugs.

Controls Most modern transit LNG stations are controlled through the use of computerized controllers. These controllers are located on the equipment in explosion proof boxes and/or in a location outside of the hazardous area. The electronic controls direct the starting and stopping of the pumps as well as opening and closing a number of control valves which are used to control flow of LNG between various station components.

Defueling is defined as removing all of the LNG inventory from a bus fuel delivery and storage system. In general, the removed LNG is pumped back to the facility LNG storage tank.

Diesel Fuel Diesel fuel is the most common fuel for heavy duty engines and is therefore a standard of comparison for other, alternative fuels.

Dike A structure used to establish an impounding area.

Diesel Volume Equivalent (DVE) The number of litres of LNG equivalent to a liter of diesel on the basis of equal thermal energy.

Emergency Shutdown Device (ESD) A device that permits the closing of LNG flow from one point to another within the fueling facility from either local or remote locations.

Fail-Safe A characteristic of a system or its elements whereby any failure or malfunction affecting safety will cause the system to revert to a state that is known to be safe.

Flammable Liquid A flammable liquid is one which has a flash point below 311 K (100 °F) and has a vapor pressure not exceeding 310 kPa (40 psia) at 311 K (100 °F).

Flammability Limits The range of fuel vapor concentrations in a fuel-air mixture over which burning can occur. Below the lower flammability limit there is not enough fuel to burn. Above the higher flammability limit there is not enough air to support combustion.

Flash Point The minimum temperature at a liquid generates vapor in a sufficient rate as to form a vapor-air mixture of concentration (close to the liquid surface) which is ignitable in a vessel as specified by appropriate test standard.

Fuel Dispenser System All the pumps, meters, piping, hoses, and controls used for the delivery of LNG to, and the removal of vapor from, a vehicle.

Fuel Storage System One or more containers, including their interconnecting equipment, that are designed, fabricated and approved for use in the mobile containment of LNG for bus power.

Fuel Tank An LNG container on board the vehicle.

Fueling Facility A facility that dispenses LNG into vehicles for use as an engine fuel.

Fueling Receptacle The mating part of the fueling connector mounted on a vehicle.

Hazard An existing or potential condition that can result in an accident.

Heat of Vaporization The amount of heat energy necessary to vaporize one unit mass (e.g., a kilogram) of liquid fuel. For comparison, the latent heat of vaporization of water is 2550 kJ/kg.

Ignition Source Any item or substance capable of an energy release of the type and magnitude sufficient to ignite any flammable mixture of gases or vapors that could occur at the site.

Impounding Area An area that is defined physically through the use of dikes or its topography at the site for the purpose of containing any spill of LNG or flammable refrigerants.

Liquefied Natural Gas (LNG) A fluid in the liquid state composed predominantly of methane and that can contain minor quantities of ethane, propane, nitrogen, or other components normally found in natural gas.

LNG Dispensers The LNG dispensers function much like a diesel dispenser. The dispenser has a liquid flow line and a vapor return line.

LNG Transport A vehicle with a double wall insulated tank that is designed to transport for commerce liquefied natural gas. Generally, "LNG transport" refers to a highway tank truck.

Lower Flammable Limit The minimum volume concentration of a combustible vapor in a mixture of vapor and air at normal temperature which can sustain the propagation of a flame in the mixture.

Mean Time Between Events (MTBE) The arithmetic mean between successive events.

Mean Time Between Hazardous Events (MTBHE) This refers to the mean time between the occurrence of critical or catastrophic hazards (Table 3-1).

Natural Gas An alternative fuel, natural gas is the same natural gas burned for heating and cooking. Natural gas varies in composition with location. Natural gas is usually more than 90 percent methane with smaller amounts of other hydrocarbons.

Pressure Relief Device A device designed to open in order to prevent a rise of internal fluid pressure in excess of a specified value due to emergency or abnormal conditions. This device can be of the reclosing or other type, such as one having a rupture disk or fusible plug that requires replacement after each use.

Relative Fuel Vapor Density The density of the fuel vapor compared to that of air. Thus, on this scale, air equals 1.00.

Risk A measure of the severity and likelihood of an accident.

Safe State System state which is deemed acceptable by the hazard resolution process (3.1.2).

Safety Critical A designation placed on a system, subsystem, element, component, device, or function denoting that satisfactory operation of such is mandatory to mitigation of unacceptable and undesirable hazards as defined in Table 3-1.

System Safety The application of engineering and management principles, criteria, and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle.

Upper Flammability Limit The maximum volume concentration of a combustible vapor in a mixture of vapor and air at normal temperature which can sustain the propagation of a flame in the mixture and which cannot sustain a stable and steady flame front throughout the mixture at higher concentrations.

Vaporizer A device other than a container that receives LNG in liquid form and adds sufficient heat to convert the liquid to a gaseous state, or a device used to add heat to LNG.

Vapor Pressure The pressure exerted by the vapors in equilibrium with its liquid at a specific temperature. ASTM D323 Test "Standard Method of Test for Vapor Pressure of Petroleum Products" measures the vapor pressure at a standard temperature of 37.8 °C (100 °F) and reports the value as "Reid Vapor Pressure."

Volume Fuel with Same Energy This is the ratio of the volumetric energy content of the fuel to that of gasoline or diesel fuel. Numerically, this is the ratio of the Lower Heating Value (LHV) in MJ/L for the fuel to the lower heating value of gasoline or diesel fuel in MJ/L.

Water Capacity This is numerically the same as the volume of water at 15.6 °C (60 °F) required to fill a fuel tank completely.

List of Acronyms

A&E	Architectural and Engineering
ACH	Air Changes per Hour
ADA	Americans with Disabilities Act, 1990
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
BOCA	Building Officials and Code Administrators (Chicago, IL)
CNG	Compressed Natural Gas
CSA	Canadian Standards Association
DVE	Diesel Volume Equivalent
EPA	Environmental Protection Agency
ESD	Emergency Shutdown
FM	Factory Mutual
FTA	Federal Transit Administration (of U.S. Dept. of Transportation)
GRI	Gas Research Institute
ICBO	International Conference of Building Officials (Whittier, CA)
LEL	Lower Explosive Limit
LFL	Lower Flammability Limit
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MMCF	Million Cubic Feet
MSHA	Mine Safety and Health Administration

MTBE	Mean Time Between Events
MTBHE	Mean Time Between Hazardous Events
NEC	National Electrical Code
NFPA	National Fire Protection Association
NRTL	Nationally Recognized Testing Laboratory
O&SHA	Operational and Support Hazard Analysis
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration (of U.S. Dept. of Labor)
PHA	Preliminary Hazard Analysis
PRD	Pressure Relief Device
RLM	Refrigerated Liquid Methane
SBCCI	Southern Building Code Congress International (Montgomery, AL)
SCF	Standard Cubic Feet
SHA	Support Hazard Analysis
SSHA	Subsystem Hazard Analysis
SSPP	System Safety Program Plan
TEFC	Totally Enclosed Fan Cooled
U.S. DOT	United States Department of Transportation
UFC	Uniform Fire Code
UFL	Upper Flammability Limit
UL	Underwriters Laboratories

Glossary of Graphic Symbols

	Information
CAUTION	Caution
OSHA	Occupational Safety & Health Administration Logo
	National Electrical Code Logo
	U.S. Department of Transportation Logo
NFPA®	National Fire Protection Association Logo

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