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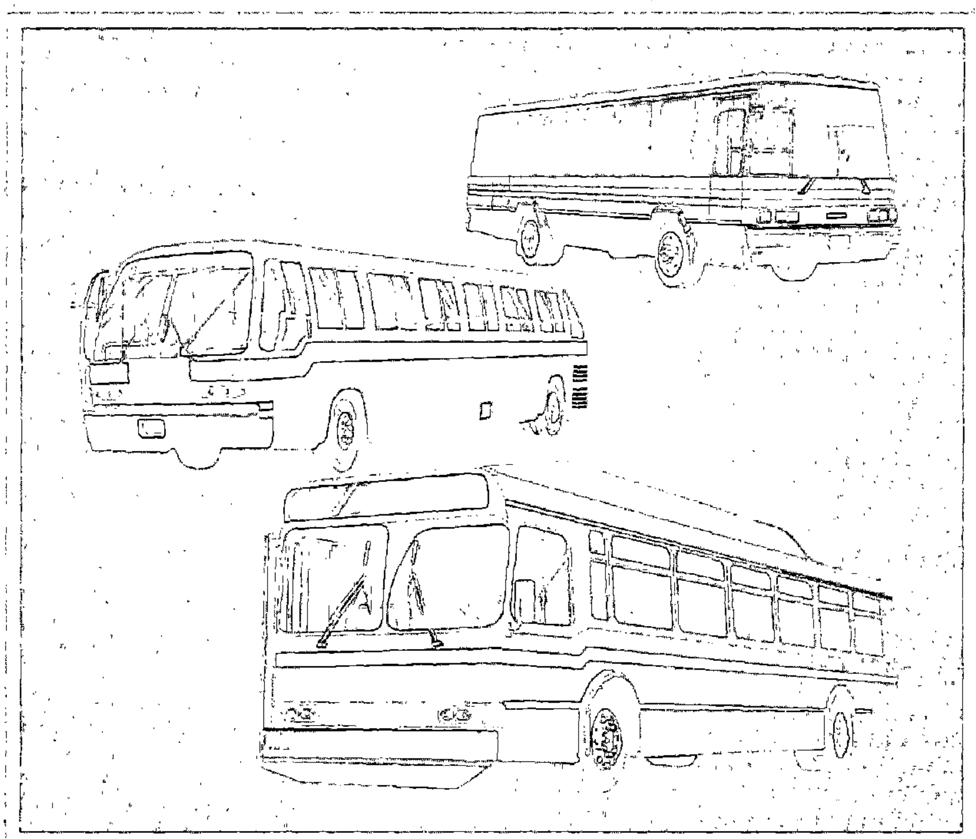
U.S. Department of Transportation

Federal Transit Administration

Clean Air Program

Design Guidelines for Bus Transit Systems Using Liquefied Petroleum Gas (LPG) as an Alternative Fuel

September 1996
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 Petroleum Gas (LPG), Compressed Natural Gas (CNG), and Methanol/Ethanol, are already being used in buses. At present, there do not exist comprehensive facility guidelines to assist transit agencies contemplating converting from diesel to other alternative fuels. This document addresses that need.

This guidelines document presents the various facility and bus design issues that need to be considered to ensure safe operation when using LPG as the alternative fuel. Fueling facility, garaging facility, and maintenance facility requirements and safety practices are indicated. Fuel properties, potential hazards, fuel requirements for specified level of service, applicable codes and standards, ventilation, electrical classification, etc., are discussed.

A system safety assessment and hazard resolution process is also. 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 are being published for CNG, LNG, and Methanol/Ethanol.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE)	**LENGTH** (APPROXIMATE)
1 inch (in) = 2.5 centimeters (cm)	1 millimeter (mm) = 0.04 inch (in)
1 foot (ft) = 30 centimeters (cm)	1 centimeter (cm) = 0.4 inch (in)
1 yard (yd) = 0.9 meter (m)	1 meter (m) = 3.3 feet (ft)
1 mile (mi) = 1.6 kilometers (km)	1 meter (m) = 1.1 yards (yd)
	1 kilometer (km) = 0.6 mile (mi)
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1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)	1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)	10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)	
MASS - WEIGHT (APPROXIMATE)	**MASS - WEIGHT** (APPROXIMATE)
1 ounce (oz) = 28 grams (gm)	1 gram (gm) = 0.036 ounce (oz)
1 pound (lb) = .45 kilogram (kg)	1 kilogram (kg) = 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)	**VOLUME** (APPROXIMATE)
1 teaspoon (tsp) = 5 milliliters (ml)	1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp) = 15 milliliters (ml)	1 liter (l) = 2.1 pints (pt)
1 fluid ounce (fl oz) = 30 milliliters (ml)	1 liter (l) = 1.06 quarts (qt)
1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
1 pint (pt) = 0.47 liter (l)	1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 quart (qt) = 0.96 liter (l)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
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)	**TEMPERATURE** (EXACT)
°C=5/9(°F - 32)	°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES 0 1 2 3 4 5

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

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

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

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

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The information indicated in this document is based on publicly available information, NFPA Codes and Standards, technical input from several people in the LPG industry, transit systems, architect and engineering firms, and trade associations. The authors wish to thank all persons who provided technical input, suggestions, and comments on draft version of this document. We express our special thanks to Mr. William Butterbaugh for communicating the National Propane Gas Association's (NGPA's) comments. Our thanks are also due to Messrs. Frank Lonyai (Orange County Transportation Authority–OCTA, CA), Theodore Lemoff (National Fire Protection Association), and Scott Stookey (Fire Protection Division, Austin Fire Department, TX) for their thorough review of the draft and valuable comments and suggestions. Other suggestions are also acknowledged that were provided by the members of an informal committee of industry representatives that was convened to provide input for the preparation of the "Design Guidelines for Transit Bus Facilities Using Alternative Fuels".

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Chapter 1
Introduction

At present over 1,000 transit buses in revenue service in the United States use alternative fuels (fuels other than diesel or gasoline) and 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, comprehensive guidelines for the safe design and operation of alternative fuel facilities and vehicles do not exist for the 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 Bus Transit Systems Using Alternative Fuels."

This report provides design guidelines for the safe use of Liquefied Petroleum Gas (LPG). It forms a part of the series of individual monographs being published by the FTA on (the guidelines for the safe use of) Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), 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. The use has also been encouraged by the FTA's Alternative Fuels Initiative (AFI) initiated in 1988 and due to the several demonstration programs funded by the FTA. The AFI involved the field testing, demonstration and assistance in revenue service placement of buses powered by CNG, LNG, 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 liquefied petroleum gas (LPG) 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 personnel. Therefore, the document also includes design issues related to vehicle safety and personnel training issues.

[1] A series of documents similar to this in scope and content are to be published by the U.S. DOT/FTA on other alternative fuels, namely, CNG, LNG, Methanol/Ethanol.

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

- Fuel properties relevant to safe operations.
- 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.
- 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 local conditions.

- This document references sections of national codes or regulations. Such references to particular sections of the standards or the regulations is NOT intended to convey the impression that only those sections apply. It is, however, intended to get the reader started or even directed to the appropriate sections in the standards or the codes. It is recommended that the entire 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 that 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 text. All terms highlighted in 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 section 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 two organizations: 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, a symbol is used to highlight **additional information.** This symbol appears in the list of graphic symbols at the end of this document and is identified by a circled large lowercase *i*; the information is bolded and enclosed in a box.

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 text to follow. 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 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 compressed natural gas (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.

- NFPA 58 — Standard for the Storage and Handling of Liquefied Petroleum Gases. This standard describes the minimum requirements that LPG facilities and vehicles must meet to ensure safety.

- 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 Petroleum Gas (LPG)

2.1 KEY PHYSICAL PROPERTIES

2.1.1 General Properties

Liquefied Petroleum Gas (***LPG***) is a co-product of natural gas and of refinery operations. It consists mainly of propane with smaller amounts of propylene, butane, and other light hydrocarbons. It is often referred to as LP-Gas or Propane. It is an odorless, colorless gas that is stored as a liquid under moderate pressure. An odorant is added in small amounts to the fuel to facilitate detection of even small leaks of gas from containers. The odorant gives the gas a distinctive smell. The average person can smell the odorant in propane when the concentration of propane in air is at 20% of the Lower Flammability Limit (LFL).

Selected properties of propane are indicated in Table 2-1. Propane has a molecular weight which is higher than that of air. It is a gas at ambient temperature and pressure. However, when propane is compressed to moderate pressures >1 MPa (>125 psi) at normal atmospheric temperature 294 K (~70 °F) it liquefies. Propane is generally stored at ambient temperature in ASME pressure vessels or in DOT cylinders under moderate pressure. The tank pressure depends on the storage temperature. For pure propane 294 K (70 °F), the pressure in the ***container*** will be 860 kPa (110 psig); at 311 K (100 °F), the pressure will be 1.32 M Pa (174 psig). Commercial grade propane has a slightly higher vapor pressures than for pure propane. For purposes of comparison, values of selected properties of diesel are also indicated in Table 2-1.

2.1.2 Flammability and Associated Hazards

At concentrations less than 2%, the Lower Flammability Limit (LFL), the gas/air mixture is "too lean" to burn. Above 9.5% the Upper Flammability Limit (UFL), the gas/air mixture is "too rich" to burn. If the concentration of propane vapor in a fuel/air mixture is between 2 and 9.5%, it can burn or even explode under certain confined conditions, if a source of ignition is present. The ignition source could be a cigarette, a floor mounted open-flame heater (such as a "salamander"), electric hand tools, motors or a hot light. Surfaces with temperatures as low as 722 K (840 °F) should be considered as potential ignition sources.

Table 2-1
Selected Properties of LP-Gas (Commercial Propane and Commercial Butane) and Comparison with Selected Properties of Diesel

Property Item	At Condition		Value of Property Parameter					
			Commercial Propane		Commercial Butane		Diesel*	
	SI Units	Convent-ional Units	SI Units	Convent-ional Units	SI Units	Convent-ional Units	SI Units	Convent-ional Units
Molecular Weight			44.1 kg/kmole		58.134 kg/kmole		N/A	
Boiling Point (at Atmospheric Pressure)	0.1 M Pa	14.7 psia	231.3 K	-43.73 °F	263.9 K	15 °F	N/A	N/A
Vapor Pressure	277.8 K	40 °F	0.54 M Pa	63.8 psig	0.12 M Pa	2.9 psig		
	294.4 K	70 °F	0.98 M Pa	127 psig	0.22 M Pa	17 psig		
	311.1 K	100 °F	1.45 M Pa	196 psig	0.36 M Pa	37 psig		
	313.9 K	105 °F	1.55 M Pa	210 psig	0.38 M Pa	41 psig		
	327.8 K	130 °F	2.08 M Pa	287 psig	0.58 M Pa	69 psig		
Liquid Density	289.0 K	60 °F	504 kg/m^3	31.45 lb/cft	582.1 kg/m^3	36.32 lb/cft	850 kg/m^3	53 lb/cft
Vapor Density (at Atmospheric Pressure)	Boiling Point		2.42 kg/m^3	0.151 lb/cft	1.6 kg/m^3	0.1 lb/cft	N/A	N/A
Specific Gravity of Vapor (Air = 1)	289.0 K	60 °F	1.5		2.01			
Flammability Limits in Air								
Lower	289.0 K	60 °F	2.15 % by volume		1.55 % by volume		0.6 %by volume	
Upper	289.0 K	60 °F	9.60 % by volume		8.60 % by volume		5.5 % by volume	

Property Item	At Condition		Value of Property Parameter					
			Commercial Propane		Commercial Butane		Diesel*	
	SI Units	Convent-ional Units	SI Units	Convent-ional Units	SI Units	Convent-ional Units	SI Units	Convent-ional Units
Ignition Temperature in Air			767-878 K	920-1,120 °F	750-810 K	900-1,000 °F	503 K	445 °F
Maximum Flame Temperature in Air			2,253 K	3,595 °F	2,264 K	3,615 °F	N/A	N/A
Latent Heat of Liquid			428 kJ/kg	184 Btu/lb	388.5 kJ/kg	167 Btu/lb	—	—
(Vaporization at Boiling Point)			215.5 MJ/m^3	773 Btu/gal	225.2 MJ/m^3	808 Btu/gal	—	—
Heating Value								
Higher			50.1 MJ/kg	21,548 Btu/lb	49.4 MJ/kg	21,221 Btu/lb	45.6 MJ/kg	19,600 Btu/lb
Lower			40.5 MJ/kg	17,140 Btu/lb	45.8 MJ/kg	19,665 Btu/lb	40.5 MJ/kg	17,410 Btu/lb

Source: *NFPA 58 (1995)*
ASHRAE (1969)

**Refers to #1 Diesel*

If liquid is released from a pressurized state, it readily flashes forming a mixture of cold vapor and liquid droplets which is readily vaporize when air is mixed. If the release occurs through a hole in the liquid wetted wall of the tank, a two phase jet results. The density of this initial two phase mixture will be greater than that of the surrounding air because of the low temperature of the vapor, high molecular weight, and the presence of fine droplets of liquid. Hence, the vapor cloud released is expected to disperse close to the ground, even as it mixes with air.

Since the propane exiting the ***container*** is heavier than air, in large leaks propane will tend to disperse close to the ground in still air conditions and accumulate in low places such as pits or trenches, if present. When a breeze or a wind is present, the vapor plume (or cloud) is diluted by entrainment of air. The rate of dilution of a cloud of propane by the atmosphere depends on the size of the cloud as well as on the atmospheric conditions. Small leaks, however, will tend to disperse quickly, even in a gentle breeze, without any vapor "fall" to the ground. The distance from the release point beyond which the plume (or a cloud) is not flammable depends on a number of factors including: the release rate; the wind speed and atmospheric turbulent conditions; topography; and presence of structures and buildings. Relatively small leaks will be diluted to below LFL within a short distance.

2.1.3 Other Hazards

Propane is considered nontoxic and is nonpolluting to ground and surface waters. It is a simple asphyxiant—displacing the necessary oxygen that a person requires. The primary fire ***hazard*** from propane releases arises from the vapor fire; that is, ignition of a propane-air dispersed cloud and the propagation of a deflagration type fire. The fire will present a thermal radiation ***hazard*** in a zone close to the boundaries of the dispersed cloud. If the propane-air mixture is in confined areas and is ignited, an explosion can result. Ignition of a jet of vapor issuing from a hole in a tank or a pipeline will lead to the formation of a jet fire.

Every propane tank is equipped with a pressure relief valve in addition to (flow) control valves. The pressure relief valve is designed to open and relieve excess pressure inside the tank when the tank pressure exceeds a certain pre-determined value and to close when the pressure inside the ***container*** is reduced to below that setting. Therefore, under a condition of short duration exposure to a fire the tank is protected by the pressure relief valve.

If, however, a propane tank of the size used on a bus as a ***fuel tank*** is engulfed in a liquid hydrocarbon fuel (gasoline or diesel) for a long duration, it is likely that the strength of the tank wall not in contact with liquid propane will be reduced due to high temperature. As a consequence of such weakening, the tank may fail releasing all of the pressurized propane inventory into the fire very rapidly. Such an event would be a boiling liquid expanding vapor explosion (***BLEVE***). **It should be noted**, however, that such ***BLEVE*** **phenomenon has not occurred** in any recorded transportation accidents involving ***LPG*** tanks on pickup trucks, police automobiles, and incidents involving LP powered school buses. Some of these accidents involved exposing the LP tank to an external fire.[1]

It should be emphasized that ***BLEVE*** phenomenon is an extremely low probability event. By instituting appropriate emergency response action after an LP bus accident, the occurrence of a ***BLEVE*** can be virtually eliminated.

2.1.4 Fuel Composition and Diesel Equivalence

Propane engine fuel, often designated HD-5, is a popular alternative fuel for light and medium duty vehicles. The HD-5 designation for engine grade fuel limits to 5% the amount of propylene and to 2.5% the volume of butanes and heavier hydrocarbons that are often in greater amounts in commercial propane. The fuel has only seen limited application in heavy duty engines for trucks and transit vehicles. Both Cummins and Detroit Diesel, have worked with the fuel, but do not currently offer engine products that utilize the fuel.[2]

While HD-5 propane is available in most of the United States, there has been significant experience and satisfactory operation on a local basis with commercial propane as an engine fuel or with other fuel specifications.

Light duty engines that are compatible with propane are available from all major vehicle suppliers, including Ford, Chrysler and General Motors. These engines are often delivered with a temporary gasoline fuel system installed to power the vehicle and "upfitted" to propane by a factory authorized conversion shop or by a qualified after-market conversion facility.

Propane has been used extensively as a fuel for forklift trucks and its use is well understood in the transportation industry. Transit buses powered by propane were used in Chicago and San Antonio in the 1950s and performed well. Although heavy duty buses are currently not available from any

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[1]The general construction and other requirements for a fuel ***container*** (i.e., a ***fuel tank***) forming part of a vehicle engine fuel system using ***LP-Gas*** are indicated in NFPA 58 §8-2.2. At this time there are no specific U.S. DOT or any other regulatory agency specifications or requirements for LP ***fuel tank*** (for use in buses or heavy trucks) protection against a fire exposure. The National Highway Traffic Safety Administration (NHTSA) of U.S. DOT is expected to develop specifications for LP fuel tanks for use on the road vehicles.

[2]The Propane Vehicle Council, National Propane Gas Association, and Propane Gas Association of Canada have contracted with Detroit Diesel Corp. for the development of a 250-275 HP, Series 50 propane engine for heavy duty vehicle use *(Meyers, 1995)*. The project is expected to be completed in December 1996. Caterpillar Corp. makes the 3306 and 3406 engines for propane. Cummins has two L-10 propane engines operating in the Orange County, CA. It is also known that Cummins has plans to develop the propane versions of its 6B and M11 engines *(Butterbaugh, 1996)*.

OEM supplier, light duty 22 feet to 28 feet vehicle propane conversions are available from factory authorized "upfitters."

Propane offers important air quality and energy security benefits that cannot be obtained with typical ***diesel fuel***. Lower carbon monoxide, hydrocarbon (HC), and nitrogen oxides (No_x) emissions make these fuels more acceptable from an environmental perspective.

Propane has been used as an engine fuel for over 80 years. Any four-cycle gasoline engine can be converted easily to propane operation. Most diesel engines can be refitted to operate on propane as spark ignition engines.

Table 2-2 shows the comparison of ***LPG*** requirements in buses for diesel equivalent service. Note that on a theoretical basis about 1.5 times more volume of propane has to be carried in tanks for every unit volume of diesel to obtain the same driving range.

2.1.5 LPG Supply Quality

Propane is normally supplied through distributors and is delivered to user site by truck. Current ***LPG*** fuel supply content variations do not appear to cause engine problems. ***LPG*** is produced within the continental United States as a by-product of natural gas production and crude oil refining. It is also available from overseas locations via large ships. Net imports of ***LPG*** to the U.S. are approximately 9% of the total supply, most of which comes from North America, primarily Canada, by pipeline.

Table 2-2
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
Diesel #2	36,235	MJ/m^3	130,000	Btu/gal
Liquefied Petroleum Gas (LPG)	23,620	MJ/m^3	84,800	Btu/gal

2. DIESEL EQUIVALENT VOLUMES (DEV) FOR ***LPG***				
Parameter	SI Units		Conventional Units	
	Value	Units	Value	Units
DEV #1†	1.487	liter of LPG/ liter of diesel	1.487	gal/gal of diesel
DEV #2‡	1.534	liter of LPG/ liter of diesel	1.534	gal/gal of diesel
500 liters of #1 diesel	820*	liter of ***LPG***	—	—
125 gallons of #1 diesel	—	—	200*	gal. of ***LPG***

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

* This equivalency value is based on the assumption that an ***LPG*** engine will be about 10% less efficient than its diesel counterpart (on energy equivalence basis). This number indicates the volume of ***LPG*** that must be carried on-board an ***LPG*** 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 ***LPG*** transit bus fueling facility are discussed in this section. An ***LPG*** fueling facility consists of the following subsystems:

- Cargo (***LPG***) transfer/unloading system.
- Storage tanks and associated piping and pumps.
- Fuel transfer and dispensing system.
- Safety systems (detectors, alarms, and fire suppression).

The operation of ***LPG*** transfer to vehicle mounted containers (including the ***fuel tank***) is permitted to take place only outdoors or under a weather shelter or a canopy (NFPA 58 §3-2.3). As such, all fueling facilities are outdoor facilities.

Discussed below are the applicable regulations, codes, national standards, and other issues related to system safety aspects of an ***LPG*** bus transit fueling facility including structural, ventilation, and electrical classification.

2.2.1 Applicable Regulations, Codes, and Standards

The following regulations, codes, and standards are applicable to one or more elements of a ***LPG*** storage, transfer, or use facility and storage and maintenance of LP powered vehicles.

OSHA

29 CFR, Part 1910.110 "Storage and Handling of Liquefied Petroleum Gases"

NFPA

NFPA 58: Standard for the Storage and Handling of Liquefied Petroleum Gases, 1995 Edition

NFPA 88A: Standards for Parking Structures

NFPA 88B: Standards for Repair Garage, 1991 Edition

NFPA 70: National Electrical Code, 1996

NFPA 58 is an American National Standard, and as such, is used as the basis of regulation by virtually every state. NFPA 58 is extensive in that it covers the design requirements in a wide range of LP applications and use. The U.S. Federal Regulations (OSHA 29 CFR, 1910.110) focus is especially employee safety. However, these regulations also stipulate requirements for the location of storage vessels, storage vessel design, transfer piping, safety equipment/appurtenances, ***LPG*** storage inside buildings and in vehicles, etc. Consideration should be given by the transit agency and/or its design contractor before either facility modification or new facility designs are initiated to thoroughly review both NFPA 58 and 29 CFR 1910.110.[3] Most state and local regulations adopt American National Standards, such as NFPA 58 and NFPA 70, as the text of their respective regulations. However, other states have developed their own regulations (for example, Texas Railroad Commission Regulations on ***LPG***). Also, some local jurisdiction in several southern and western states have adopted the requirements of the Uniform Fire Code (UFC), Building Officials and Code Administrators (BOCA) fire code, Southern Building Code Congress International (SBCCI) Code, etc. These standards have all adopted NFPA 58; however, they may, in addition, have other requirements (i.e., rules on garaging). Transit agencies must comply with any local and state fire and building regulations that are applicable.

It is noted, however, that the above codes, standards, and regulations are broad in scope—there are no codes/standards specific to only an ***LPG*** bus transit facility. To address specific design issues related to ***LPG***, the transit agency should consider undertaking a ***hazard*** analysis in accordance with Section 3 of this report. Hence, certain interpretations of applicability as well as judgment will have to be exercised in using the different requirements of the standards.

2.2.2 Fueling Dispenser Location and Installation Provisions

It is important to locate the fuel dispensing system at a safe place away from occupied buildings and critical facility system components. Detailed requirements for the location of transfer operations are indicated in NFPA 52 §3-2.3. The following table indicates the minimum distance between the dispenser and other objects.

NFPA®

Table 3-2.3.3 Distance Between Point of Transfer and Exposures

Part	*Exposure*	*Min. Horizontal Distance Feet*	*(Meters)*
1.	*Buildings* with fire-resistive walls.***	*10*	*(3.1)*
2.	*Buildings with other than fire-resistive walls.***	*25*	*(7.6)*
3.	*Building wall openings or pits at or below the level of the point of transfer.*	*25*	*(7.6)*

[3]OSHA has adopted NFPA 58, 1969 edition. It is OSHA's policy that if a regulated entity complies with the requirements of a later edition of an adopted standard, which contravenes the regulations, OSHA, at worst, may issue an administrative citation, rather than impose a penalty. (Lemoff, 1996)

Table 3-2.3.3 Distance Between Point of Transfer and Exposures			
Part	Exposure	Min. Horizontal Distance Feet	(Meters)
5.	Outdoor places of public assembly, including school yards, athletic fields, and playgrounds.	50	(15)
6.	Public ways, including public streets, highways, thoroughfares, and sidewalks.		
	a. From points of transfer in **LP-Gas** dispensing stations and at vehicle fuel dispensers.	10	(3.1)
	b. From other points of transfer.	25	(7.6)
7.	Driveways.†	5	(1.5)
8.	Mainline railroad track centerlines.	25	(7.6)
9.	Containers†† other than those being filled.	10	(3.1)
10.	Flammable and Class 2 combustible liquid‡ dispensers and aboveground and underground containers.	20	(6.1)

Notes:
**Buildings, for the purpose of the table, include structures such as mobile homes, tents, and box trailers at construction sites.*
***Walls constructed of noncombustible materials having, as erected, a fire resistance rating of at least one hour as determined by NFPA 251, Standard Methods of Fire Tests of Building Construction and Materials.*
†Not applicable to driveways and points of transfer at vehicle fuel dispensers.
*††Not applicable to filling connections at the storage **container** or to dispensing vehicle fuel dispensers units 2,000 gallon (7.6 m^3) water capacity or less when used for filling containers not mounted upon vehicles.*
‡NFPA 30 defines these as follows:

*Flammable liquids include those having a flash point below 100 °F (37.8 °C) and having a **vapor pressure** not exceeding 40 pounds per square inch (absolute) (2.068 mm Hg) at 100 °F (37.8 °C).*

Class II combustible liquids include those having a flash point at or above 100 °F (37.8 °C) ` below 140 °F (69 °C).

The requirements of NFPA 58 §3-2.3 and §3-9 "Vehicle Fuel Dispenser and Dispensing Stations" should be carefully reviewed and the stipulations should be implemented.

2.2.3 Structural and Mechanical

2.2.3.1 Storage *container.* An outdoor, above ground fixed ***LPG*** tank(s) will most likely be positioned on a transit property. These tanks should be ASME containers and be located at safe distances from buildings, public access, and other equipment. The following safe distances between containers and important buildings and between containers are specified in 29 CFR, §1910.110(a)(6)(f)(ii).

OSHA

Table H-23

Water capacity per container	*Minimum distances*		
	Containers		*Between above-ground containers*
	Under-ground	*Above-ground*	
*Less than 125 gals.**	*10 feet*	*None*	*None*
125 to 250 gals	*10 feet*	*10 feet*	*None*
251 to 500 gals	*10 feet*	*10 feet*	*3 feet*
501 to 2,000 gals	*25 feet***	*25 feet***	*3 feet*
2,001 to 30,000 gals	*50 feet*	*50 feet*	*5 feet*
30,001 to 70,000 gals	*50 feet*	*75 feet†*	
70,001 to 90,000 gals	*50 feet*	*100 feet†*	

If the aggregate water capacity of a multi-container installation at a consumer site is 501 gallons or greater, the minimum distance shall comply with the appropriate portion of this table, applying the aggregate capacity rather than the capacity per* ***container**. If more than one installation is made, each installation shall be separated from another installation by at least 25 feet. Do not apply the MINIMUM DISTANCES BETWEEN ABOVE-GROUND CONTAINERS to such installations.*
The above distance requirements may be reduced to not less than 10 feet for a single* ***container *of 1,200 gallons water capacity or less, providing such a* ***container*** *is at least 25 feet from any other* ***LP-Gas container*** *of more than 125 gallons water capacity.*
†¼ of sum of diameters of adjacent containers.

Note: the above table is identical to Table 3-2.2.2 of NFPA 58.

The design requirements for ASME containers are specified in NFPA 58, Section 3-2.4.2. The requirements for ***container*** appurtenances are specified in NFPA 58, §3-2.5.

LP storage containers are not permitted to be filled to their full water capacity. The provisions in NFPA 58 for filling a propane tank typically result in a maximum of about 85% of the actual volumetric capacity of the tank. The resulting vapor space provides adequate expansion room for the liquid phase as the result of an increase in ambient temperature. Pressure relief valves have to be provided on all storage tanks (NFPA 58, §2-3.2) to relieve pressure in the tank well below the design failure pressure of the tank. Vapor venting requirements are indicated in NFPA 58, §4-3.2.1.

2.2.3.2 Transfer Piping. Liquid is transferred from the storage ***container*** to the dispensing unit (bus fueling hose end) by a pump. Safeguards are necessary to prevent the uncontrolled discharge of ***LP-Gas*** in the event of failure in the hose or swivel type piping. This should be accomplished by complying with the requirements of NFPA 58 §3-3.3.8, namely, by providing:

- an excess flow valve; and
- an emergency shutoff valve.

Proper design and equipment installation can further limit the quantity of product released in the case of a vehicle pull away. These designs may include placement of an emergency shut off valve at a bulkhead, breakaway connection at the dispensing unit (which shuts off product flow in the case of hose break), and other similar designs. It is prudent to consider several different design approaches and use the one which will result in a minimum product release in the case of a vehicle pull away. Reference should be made to NFPA 58, §3-9.4 for other provisions related to the design requirements for dispensing units.

2.2.4 Ventilation

There are no specific ventilation standards for ***LPG*** fueling stations, because of the requirements (NFPA 58 §3-2.3.1(b)) that all transfer operations take place outdoors. If a weather shelter or a canopy is provided, then the area should be well ventilated and the perimeter should not be enclosed for more than 50% (NFPA 58, §3-9.3.2).

2.2.5 Electrical Equipment

All electrical machinery, wiring, instruments, gages, and other equipment used in ***LPG*** installations should conform to NFPA 70 requirements. In order to minimize possibilities of ignition of LP-Gas–air mixtures (resulting from the normal or accidental release of nominal quantities of liquid or vapor from ***LP-Gas*** systems) several areas in the fueling area and bus storage and maintenance areas of ***LPG*** facilities are electrically classified in NFPA 58 and 29 CFR §1910.110, Table H-28.

Very specific requirements for electrical classifications for ***LPG*** facilities are provided in both NFPA 58, Table 3-7.2.2 and also in 29 CFR, 1910.110, Table H-28. For example, vehicle fuel dispenser is classified as Class I, Division 1 for the space within the dispenser enclosure, and 0.5 m (18 inches) from the enclosure exterior up to an elevation of 1.2 m (4 feet) above the dispenser base. The space up to a height of 0.5 m (18 inches) and 6.1 m (20 feet) horizontally is classified as Class I, Division 2. Electrical equipment design for a bus facility not specifically covered in the above codes and standards should be developed using the ***hazard*** analysis process from Section 3 of this document.

The NFPA 58 §3-9.5.2 requires the provision of a remote switch, away from the dispensing station, to shut off the power in the event of fire or accident near the fueling facility.

The following electrical class definitions and statements on their applicability are reproduced from NFPA 70 "National Electrical Code, 1981."

500-4. Class 1 Locations. *Class 1 locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. Class 1 locations shall include those specified in (a) and (b) below.*

(a) Class 1, Division 1. *A Class 1, Division 1 location is a location: (1) in which ignitable concentrations of flammable gases or vapors exist under normal operating conditions; or (2) in which ignitable concentrations of such gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or (3) in which breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might also cause simultaneous failure of electric equipment.*

> *This classification usually includes locations where volatile flammable liquids or liquefied flammable gases are transferred from one* ***container*** *to another; interiors of spray booths and areas in the vicinity of spraying and painting operations where volatile flammable solvents are used; locations containing open tanks or vats of volatile flammable liquids; drying rooms or compartments for the evaporation of flammable solvents; locations containing fat and oil extraction equipment using volatile flammable solvents; portions of cleaning and dyeing plants where flammable liquids are used; gas generator rooms and other portions of gas manufacturing plants where flammable gas may escape; inadequately ventilated pump rooms for flammable gas or for volatile flammable liquids; the interiors of refrigerators and freezers in which volatile flammable materials arc stored in open, lightly stoppered, or easily ruptured* ***containers****; and all other locations where ignitable concentrations of flammable vapors or gases are likely to occur in the course of normal operations.*

(b) Class 1, Division 2. *A Class 1, Division 2 location is a location: (1) in which volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed* ***containers*** *or closed systems from which they can escape only in case of accidental rupture or breakdown of such*

containers *or systems, or in case of abnormal operation of equipment; or (2) in which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilating equipment; or (3) that is adjacent to a Class 1, Division 1 location, and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.*

> *This classification usually includes locations where volatile flammable liquids or flammable gases or vapors are used, but which, in the judgment of the authority having jurisdiction, would become hazardous only in case of an accident or of some unusual operating condition. The quantity of flammable material that might escape in case of accident, the adequacy of ventilating equipment, the total area involved, and the record of the industry or business with respect to explosions or fires are all factors that merit consideration in determining the classification and extent of each location.*

2.2.6 Safety Control Systems

No specific requirements for providing detection instruments and other safety alarm devices in fueling facilities are indicated in either NFPA 58 or 29 CFR 1910 regulations. However, consideration should be given to installing several or all of the following types of detection instruments at suitable locations within the fueling facility (near the dispensing unit).

1. Hydrocarbon concentration sensor located at about 0.5 m (18 inches) above the floor and close to the dispensing unit.
2. Fire or high temperature detection (IR or UV instruments) devices.
3. Audible and visible alarm systems to warn the fueler and other employees nearby of a leak of ***LPG***.
4. Closed circuit TV monitors.
5. Voice communication equipment (cellular or wired telephone at a protected but close by location, walkie-talkie, etc.).
6. Emergency fueling facility shut down switch.

Consideration should be given to establishing the details of use, location, and sensitivity levels associated with the detection instruments and other safety devices using the ***hazard*** analysis and resolution process performed for the specific facility in accordance with Section 3 of this document.

2.2.6.1 Fire Protection. The provision of adequate level of fire protection at the ***LP-Gas*** transfer facility is required under 29 CFR §1910.110(d)(14) regulations, as well as under NFPA 58 §3-10 standards. 29 CFR requires the provision:

(i) of an approved portable fire extinguisher having a minimum rating of 12-B,C; and

(ii) for facilities with storage of larger than 570 m^3 (150,000 gallons) aggregate water capacity of a water hydrant system and associated hoses and equipment to fight large fires.

NFPA 58 allows the determination of using competent analysis, the best approach to fire protection, taking into consideration the availability of water supply, external fire brigade resources, their level of expertise, response time, etc. (NFPA 58 §3-10.2.3). Provision of fixed spray and monitor systems complying with NFPA 15 requirements are also acceptable as long as these systems are of sufficient size and effectiveness to wet surfaces likely to be exposed in a fire. All such analysis and options shall be performed in accordance with the requirements of Section 3 of this document.

2.2.7 Maintenance of Safety Equipment

Regular maintenance of instruments and equipment should be performed. These should include, as a minimum:

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

2. Regular testing and calibration of ***gas dispenser*** temperature compensation systems must be undertaken.

3. Regular testing and calibration of ***gas dispenser*** excess flow and fill shutdowns and verification of ***LPG*** emergency shutdowns must be enforced.

4. Regular inspection of ***LPG*** bus piping systems and components including ***pressure relief devices (PRDs)*** must be undertaken.

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 ***hydrocarbon gas*** detectors, if provided, should be done on a six-month interval or per manufacturer's recommendations, whichever is more often. Infrared and ultraviolet fire sensors should be inspected regularly.

As a final check, it is recommended that whenever any person completes the work on classified electrical enclosures or devices, a trained supervisor verify the integrity of the device after the maintenance is complete.

2.3 BUS STORAGE FACILITY

A bus storage facility is a building where buses are parked for long periods of time, i.e., 12 or more hours (dead vehicle storage). Issues relating to design considerations for such buildings for storage of ***LPG*** fueled buses are discussed in this section. In certain climates, ***LPG*** transit buses are stored outdoors. Outdoor parking does not present a significant area of safety concern, and therefore is not discussed in this document.

The relevant codes and standards that are applicable to and which should be followed in the design of ***LPG*** vehicle parking areas include:

NFPA®

NFPA 58: Standard for the Storage and Handling of Liquefied Petroleum Gases

OSHA

29 CFR §1910.110(e)(14): Garaging LP-Gas-Fueled Vehicles

NFPA 88A standards are not specifically applicable to transit facilities. However, NFPA 88A is the only standard which defines dead storage facilities. Only buildings meeting the definition in NFPA 88A (or use) of a parking facility are discussed in this section. Typically, garages without physical barriers between parking and maintenance of vehicles (not for vehicle dead storage) are discussed in Section 2.4 of this document.

2.3.1 Design Overview

The principal concern in the design of the storage facility should be to minimize the potential for ignition of ***LPG*** vapors that are generated by an accidental release of ***LPG*** from the bus fuel system. Potential release scenarios and ignition sources should be identified and countermeasures should be implemented in the design. These countermeasures may include (but not be limited to): providing adequate ventilation; enhanced air flow in case of a release; elimination of electrical ignition sources by removing sparking/arcing equipment; and classification of electrical systems, etc.

It should be noted that ***LPG*** vapor is heavier than air and has dispersion characteristics similar to that of gasoline vapor. However, because of differences in the volatility of gasoline and ***LPG*** (liquid) at ambient pressure, considerably more mass of ***LPG*** vapor is generated in a given time compared to the mass of gasoline vapors liberated in the same duration of time from an equivalent mass of gasoline release. To the extent that two vapors have similar (heavier-than-air) characteristics, many of the safety design requirements (for ventilation and areas of electrical classification) for garaging gasoline fueled and LPG fueled vehicles should be considered to be similar. The design should, however, note that gasoline vapors are heavier than LPG vapors by a factor ranging between 1.5 and 2.5.

Appropriate ***hazard*** analysis should be undertaken to identify potential ignition sources as well as fuel release scenarios. The procedure indicated in Section 3 should be used to develop appropriate techniques to minimize the hazards.

2.3.2 Indoor Parking Facilities

OSHA Regulations (29 CFR §1910.110(e)(14)) allow indoor parking of LP-Gas-fueled vehicles provided there are no leaks in the fuel system and the fuel tanks are not filled beyond the allowed maximum filling density (discussed in Section 2.2.3 of this document). NFPA 58 requires the following to be complied with for indoor parking of ***LPG*** powered vehicles:

NFPA®

8-6 Garaging of Vehicles.

*Vehicles with **LP-Gas** engine fuel systems mounted on them and general purpose vehicles propelled by **LP-Gas** engines shall be permitted to be stored or serviced inside garages, provided:*

*(a) The fuel system is leak-free, and the **container(s)** is not filled beyond the limits specified in Chapter 4.*

*(b) The **container** shutoff valve is closed when vehicles or engines are under repair except when engine is operated.*

(c) The vehicle is not parked near sources of heat, open flames, or similar sources of ignition, or near inadequately ventilated pits.

No specific requirements for vapor concentration detection is indicated in either NFPA 58 or NFPA 88A. However, it is prudent to provide vapor concentration sensing instruments within the indoor facility where ***LPG*** buses will be parked. These instruments should be located close to the floor level. The number of instruments and their locations should be determined in accordance with the ***hazard*** resolution process of Section 3 of this document.

The requirement for construction of structures or buildings are indicated in NFPA 58 §7-2.1. These requirements should be followed.

2.3.2 Electrical Systems

Electrical classification of equipment or areas in bus parking garages are not discussed in either NFPA 58 or in 29 CFR 1910 regulations. It is prudent to design the electrical system components used within the garage to conform to Class I, Division 2 standards, at least up to a height of 2 m (~6 ft) above the ground level. All motors, switches, relays, etc., should be of the nonsparking type. Also, electrical heating elements that can attain temperature above 700 K (800 °F) should not be used. The requirements of NFPA 58 §3-7 "Ignition Source Control" should be reviewed carefully and required design changes to eliminate potential electrical (and other) ignition elements should be implemented.

2.3.3 Ventilation and Heating

The indoor bus storage building must be well ventilated using air inlets and outlets close to the ground. NFPA 58, §7-2.2.1 requires that these air passages be not more than 0.15 m (6 inches) above the ground. Also, the arrangement of the ventilation system should be such that, to the extent possible, a uniform flow of air is maintained throughout the parking facility. When mechanical ventilation is used, the air circulation rate should be at least equal to 0.3 $m^3/min/m^2$ (1 $cft/min/ft^2$) of floor area (NFPA 58 §7-2.2.1(a)). Natural ventilation can also be used provided that openings for air infiltration and exit are provided in the building side walls. Each opening should be larger than 325 cm^2 (50 sq in) and should be spaced not greater than 6 m (20 ft) apart. Also, the total wall opening should not be less than 70 cm^2/m^2 (1 sq in/ft^2) of floor area.

The principal function of ventilation is to ensure that flammable pockets of gas do not accumulate within the building, especially near any potential ignition sources, within the building. The building designer must keep this goal in mind and provide adequate ventilation flow if the minimum requirements are deemed to be inadequate. The need for and extent of ventilation should be determined as a part of the ***hazard*** analysis process outlined in Section 3 of this document.

Because of potential release of ***LPG*** from parked buses (however remote the possibility) and in keeping with the desire to eliminate all potential ignition sources, consideration should be given to ensuring that the surface temperature of any heating element present is lower than the ignition temperature of ***LPG***. ***Hazard*** analysis should be conducted for any heater design to ensure that it presents no unacceptable ignition hazards. The requirements of NFPA 58 for buildings or structures housing ***LP-Gas*** distribution facilities are as follows:

NFPA®

> ***7-2.3 Structure of Building Heating.*** *Heating shall be by steam or hot water radiation or other heating transfer medium with the heat source located outside of the building or structure (see Section 3-7, Ignition Source Control), or by electrical appliances listed for Class I, Group D, Division 2 locations, in accordance with NFPA 70, National Electrical Code (see Table 3-7.2.2).*

2.3.4 Construction of Structures/Buildings

There are no specific regulations or standards for either the materials or construction or the type of structures used for parking ***LPG*** fueled vehicles. However, NFPA 88A, Chapter 3 stipulates the building construction requirements for garages parking motor vehicles. These requirements should be reviewed in detail and the sections deemed applicable to the ***LPG*** vehicle storage should be followed.

NFPA 58 §7-2 indicates the requirements for buildings or structures housing ***LP-Gas*** Distribution Facilities. While these requirements are not applicable to an ***LPG*** vehicle garage, it is prudent to review this section carefully and implement those systems which enhance ***LPG*** vehicle storage safety. For example, the construction requirements for ***LP-Gas*** distribution facilities include:

NFPA®

7-2.1 Construction of Structures or Buildings.

7-2.1.1 *Separate buildings or structures shall be one story in height and shall have walls, floors, ceilings, and roofs constructed of non-combustible materials. Exterior walls, ceilings, and roofs shall be constructed as follows:*

(a) Of lightweight material designed for explosion venting, or

(b) If of heavy construction, such as solid brick masonry, concrete block, or reinforced concrete construction, explosion venting windows or panels in walls or roofs shall be provided having an explosion venting area of at least 1 sq ft (0.1 m^2) for each 50 cu ft (1.4 m^3) of the enclosed volume.

7-2.1.2 *The floor of such structures shall not be below ground level. Any space beneath the floor shall preferably be of solid fill. If not so filled, the perimeter of the space shall be left entirely unenclosed.*

2.3.5 Emergency Systems

The accidental release of ***LP-Gas*** should be managed by increasing the ventilation air flow, de-energizing spark producing equipment, and using electrically classified equipment. Therefore, it is important to maintain these systems in working condition even under the conditions of loss of external electrical power or brown out. A back up power supply, therefore, 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 utility providers 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. The local authority having jurisdiction and the agency's insurance underwriters should be consulted to ascertain the priority level of alarms. Typically, when a fire alarm is activated, ventilation is interrupted, and fire rated barriers are closed. Upon combustible gas detection, ventilation is increased and barriers are opened to increase air movement. One other conflict between fire and combustible gas detection systems is the energization of fire alarm bells throughout a facility. Since these bells can produce a spark, they may pose an ignition ***hazard***.

Audible alarms, if provided as a part of the emergency system, should be in compliance with the requirements of the Americans with Disabilities Act Accessibility Guidelines (ADA, 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.

2.3.6 Safety Interlocks

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

- Permitting manual resetting of tripped or equipment activated in an emergency.
- Providing audio and visual indications when combustible gas is detected or when an ***LP-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.

2.3.7 Operations in a Storage Facility

A transit system should implement other (passive) safety practices in ***LPG*** 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. Ensuring that no ***LPG*** 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.

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

3. Developing a proper written response plan for various types of ***LPG*** leak emergencies. These plans should include action items to respond to different size of 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.

4. Limiting the time the vehicle is running in the storage facility, since larger quantities of gas may be released when the vehicle is in actual operation.

5. Assuring that only minor maintenance is performed in the bus parking area. Dead engines and other assorted problems associated with any parked vehicle should be minimally addressed in the storage area. Detailed repairs should not be performed.

2.4 BUS MAINTENANCE FACILITY

A bus maintenance facility is generally a partially or fully enclosed building in which routine servicing and repairs of buses are performed. In most transit systems, this facility consists of one or more service bays consisting of either pits or lifts. In large facilities it is a common practice to service several buses at the same time within the building. Also, the designated service bays may or may not be dedicated to buses using specific types of fuels (diesel, ***LPG***).

Many of the facility design issues are common to most hydrocarbon fuels that vaporize easily and form flammable vapor mixture with air (CNG, LNG, ***LPG***). The differences lie in the specific requirements when they are specified in standards.

The definition of a repair facility can be found in NFPA 88B. Only buildings meeting those definitions (or uses) 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 ***LPG*** 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 sections below.

Discussed below are special design issues and operational practices in an ***LPG*** bus maintenance facility which should improve safety.

2.4.1 Applicable Codes and Standards

The codes whose selected sections are applicable to ***LPG*** bus maintenance facilities include:

NFPA®

NFPA 58: Standard for the Storage and Handling of Liquefied Petroleum Gases
NFPA 88B: Repair Garages

OSHA

29 CFR §1910.110(e)(14): Garaging LP-Gas-Fueled Vehicles

NFPA 70: National Electrical Code

However, there are no detailed codes exclusively applicable to bus maintenance facilities using ***LPG*** buses. Many of the above codes/regulations stipulate operational requirements for ***LPG*** service facilities rather than the specific structural design requirements.

2.4.2 Design Overview

In general, a maintenance facility design has all of the requirement of a vehicle storage facility and more. The size of a maintenance facility, in most transit systems, is smaller than a storage facility. In a maintenance facility, because of the nature of the work that is performed, there exists a higher probability of fuel release. It should be noted that in a repair facility, vehicle engines are often left running during a maintenance activity—this increases the potential for larger releases of fuel in a relatively smaller building volume. Proper design of a vehicle fuel system can minimize the quantity of fuel released if any part of the fuel system is adversely impacted. It may also be possible to reduce either the quantity of fuel released or the duration of accidental release with proper vehicle design and/or implementing operational procedures.

Because of operational similarities between a bus storage facility and maintenance facility, the design philosophy indicated in Section 2.3.1 of this document is made a part of this section by reference. Additional design requirements are discussed below.

2.4.3 Electrical Equipment

None of the codes or standards cited above have specific requirements for ***LP-Gas*** vehicle maintenance facility as a whole. However, NFPA 58 §3-7.2.2 stipulates that if a pit is present, then the electrical equipment used in the pit should conform to Class 1, Group D, Division 2 equipment requirements if there is mechanical ventilation, otherwise to Class 1, Division 1 requirements.

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.

The design modifications should be discussed with the transit agency's A&E firm, insurance carrier, local fire department, and authority having jurisdiction. It is necessary to comply with all state and local regulations and codes.

2.4.4 Ventilation and Heating

There are no specific references to ***LP-Gas*** vehicle maintenance facility ventilation in NFPA 58. However, there are requirements for buildings and structures housing ***LP-Gas*** distribution facilities (NFPA 58 §7-2.2). The transit agency should review the following requirements of NFPA 58 and discuss their applicability (to an ***LP-Gas*** vehicle maintenance facility) with the local authority having jurisdiction.

NFPA®

7-2.2 Structure or Building Ventilation.

7-2.2.1 The structure shall be ventilated using air inlets and outlets, the bottom of which shall be not more than 6 inches (150 mm) above the floor, and shall be arranged to provide air movement across the floor as uniformly as practical and in accordance with the following:

(a) Where mechanical ventilation is used, air circulation shall be at least 1 cubic foot per min per square feet (0.3 $m^3/min/m^2$) of floor area. Outlets shall discharge at least 5 feet (1.5 m) from any opening into the structure or any other structure.

(b) Where natural ventilation is used, each exterior wall [up to 20 feet (6.1 m) of length] shall be provided with at least one opening, with an additional opening for each 20 feet (6.1 m) of length or fraction thereof. Each opening shall have a minimum size of 50 square inches (32 250 mm^2) and the total of all openings shall be at least 1 square inch per square feet (720 mm^2/m^2) of floor area.

In addition, the ventilation requirement in NFPA 88B, Section 3.3 for repair garages and OSHA guidelines on normal building ventilation should be reviewed.

The goal of the ventilation design for a repair/maintenance facility should be (in addition to providing the normal air flow to flush out normal pollutants and to provide comfortable environment to the workers) to remove from the facility any vapors of ***LP-Gas*** that may be formed by a fuel release and to lower the vapor concentrations below the LFL. The ventilation design should also ensure that "pockets" of ***LP-Gas*** do not form within the building and that the process of diluting high concentration vapors (by the air flow) significant volumes of vapors in the flammable range are not produced.

The type of heating equipment that can be used in a building having ***LP-Gas*** distribution facility is indicated in NFPA 58 as follows:

NFPA®

7-2.3 Structure or Building Heating.

Heating shall be by steam or hot water radiation or other heating transfer medium with the heat source located outside of the building or structure (see Section 3-7, Ignition Source Control), or by electrical appliances listed for Class I, Group D, Division 2 locations, in accordance with NFPA 70, National Electrical Code (see Table 3-7.2.2).

Even though the above requirement is not for an ***LP-Gas*** vehicle repair facility, safety will be enhanced by following the above requirements in such a facility design.

NFPA 88B allows the use of approved unit heaters located above 2.4 m (8 feet) above ground level in repair garages. A transit agency should review local regulations, if any, specific to the use of unit heaters in an LP vehicle storage and/or maintenance facility. Other requirements related to building heating indicated in NFPA 88B, Section 3-2 should be reviewed. Where local regulations or codes exist on ***LP-Gas*** vehicle storage/maintenance building heating and ventilation, they should be followed.

2.4.5 Types of Construction

The requirements discussed in Section 2.3 of this document also apply to the vehicle maintenance facility. Also, the requirements of NFPA 220 related to the types of construction for large facilities housing vehicles should be reviewed. Also the NFPA 58 §7-2.1 on the construction of structures or buildings housing ***LP-Gas*** distribution facility should be reviewed and the applicability of its requirements to a vehicle maintenance facility should be discussed with the local authority having jurisdiction.

2.4.6 Maintenance Facility Operations

Special requirements exist in Federal Regulations and NFPA codes dealing with operations within an ***LPG*** vehicle service facility. These and other recommended practices are indicated below.

The OSHA regulations (29 CFR §1910.110(e)(14)) stipulate that:

OSHA

(14) Garaging LP-Gas-fueled vehicles.

(i) LP-Gas-fueled vehicles may be stored or serviced inside garages provided there are no leaks in the fuel system and the fuel tanks are not filled beyond the maximum filling capacity specified in paragraph (b)(12)(i) of this section.

*(ii) LP-Gas-fueled vehicles being repaired in garages shall have the **container** shutoff valve closed except when fuel is required for engine operation.*

(iii) Such vehicles shall not be parked near sources of heat, open flames, or similar sources of ignition or near open pits unless such pits are adequately ventilated.

Consideration should be given to adopting many of the requirements of NFPA 58 Section 6-6.2.3 for parking and garaging of ***LP-Gas*** cargo vehicles in the design and operation of maintenance facilities for LP fueled buses. The requirements of NFPA 58, Section 8-6 on garaging of vehicles should be assumed to be applicable to a maintenance facility also. (See Section 2.3 of this document.)

In addition to the above, the operations of the service facility should consider:

- Providing detailed instructions on safety to the maintenance staff, and identifying procedures to be followed in an emergency. These procedures should include how to respond to an incident involving a bus that may spring a leak on the premises.

- Establishing procedures to ensure that only mechanics trained in maintaining ***LPG*** systems and buses are allowed to service ***LPG*** buses.

2.4.7 Passive Safety Practices

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

2. Consideration should be given to ***defueling*** the bus outside the maintenance facility (except for very nominal pressure in the ***fuel tanks*** sufficient to move the bus in and out of the maintenance bay) when any part of the high pressure side of ***LPG*** fuel system on a bus is to be serviced unless the LPG tank can be completely isolated from the fuel system by means of a manual shut off valve located closest to the tank.

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

4. Only mechanics, trained in servicing a ***LPG*** fuel system be allowed to perform the maintenance on ***LPG*** fuel systems.

5. Adequate training and instructions should be provided to the mechanics working on the ***LPG*** fuel system on proper procedures for tightening compression fittings, mating of the same parts after removal, and testing for fuel vapor leaks.

2.4.8 Other Safety Issues Related to LPG Bus Facilities

There are a number of issues which are common to the design of the various sub-facilities in a ***LPG*** bus facility. These are highlighted in this section and discussed.

2.4.8.1 Ignition Sources. The important guiding principles in the operation of a facility where LPG-powered buses are serviced are (1) provide sufficient safeguards to **PREVENT** an ***LPG*** release, (2) remove all identifiable ignition sources in areas where ***LPG*** vapor may tend to accumulate following a release, (3) purge the area that may be subject to ***LPG*** vapors as quickly as possible, and (4) have an adequate and current emergency preparedness plan in the event of a problem.

There is considerable discussion in the industry as to the best approach to eliminate electrical ignition sources. Classifying all electrical systems in all parts of the bus facility to conform to Class I, Division 2 may not be, in some cases, economically feasible nor can it always ensure the absence of ignition. A possible approach is to ensure that there are no sparking equipment (either by elimination or by positive pressure protection per NFPA 70, Article 501-3(a)) among active electrical equipment such as relays, switches, motors, tools, gages, etc., but leave the embedded cables as non-classified.[4] This approach should be considered, especially for retrofit ***LPG*** facilities.

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[4]It is highly unlikely that cables, carrying even high currents, in a bus facility will initiate sparks.

2.5 BUS FUEL SYSTEM

Part of the planning for the inclusion of *LPG*-powered buses into fleet operations entails examining the safety and other systems in the *LPG*-powered bus itself. This examination should include the on-board fuel delivery and storage system design, components and interconnections, and the on-board vapor concentration fire 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 *LPG* buses within the existing fleet.

This section discusses a philosophy to be applied when exploring the design of the fuel delivery and storage 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 discussed. The proper selection of equipment, design parameters and preliminary maintenance procedures will offer the bus facility operating flexibility while ensuring a high degree of risk mitigation.

Detailed requirements for fuel systems on vehicles using ***LP-Gas*** to power the engines are indicated in NFPA 58, Chapter 8. These requirements cover the containers (fuel tanks), carburation equipment, piping, hose, fillings, etc. These requirements should be reviewed and followed in the vehicle fuel system design.

2.5.1 Fuel System Design Philosophy

An ***LP-Gas*** leak from a transit bus is a low probability event. However, the fuel system must be designed to minimize the quantity and duration of release to prevent potential hazards. ***LPG*** releases may be of one of the following two types:

- **Small leak event:** characterized by ***LP-Gas*** emanating from a loose fitting or a valve stem, etc.. This leak is likely to dissipate rapidly and no significant ***hazard*** will develop. Quick dissipation of gas occurs because of the facility's relative large size and air volume, as well as air currents generated by its ventilation system.

- **Large leak event:** characterized by ***LP-Gas*** emanation from a failure in the high pressure tubing or a complete discharge by a cylinder ***pressure relief device*** due to its malfunction (stuck open). This leak would be classified as a high volume release within a time duration of only a few minutes.

The design should ensure that the fuel delivery and storage system will limit the quantity of ***LP-Gas*** that can escape during a leak event.

2.5.2 Bus Vendor/Manufacturer Design Discussions

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

- explore alternative configurations for fuel components and their effectiveness.
- insure (high) component reliability and safety, especially during maintenance operations.
- perform an analysis to determine the potential for gas releases from components (either during normal operations or during accident conditions), quantity of gas that may be released, and actions that can be initiated to reduce or eliminate such releases.

Items to be explored should include 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 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 System Design Checklist

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

- Design of redundancy in fuel supply components that are susceptible to fouling and critical to engine operation.
- Provision of isolation valves for separating equipment and long runs of tubing.
- Selection of stainless steel tubing for pressure and abrasion considerations. Note other types of tubing (steel, copper, brass) are acceptable [See NFPA 58 §8-2.5(b)].

- Careful placement of pressure gauges that can be effectively used during maintenance operations.

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

- The selection and strategic placement of electrically operated solenoid valves in order to isolate the system when the bus is not operational.

- Installation of a battery disconnect switch in the engine compartment.

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

- Providing protection to critical fuel components against impact from dropped tools, road debris, and other accidental damage. Consideration should be given to providing a guard or a metal shield for the under chassis fuel tanks to reduce the potential for puncture by road debris and to provide protection against exposure to external fuel fires.

Once again, the goal is to carefully select and place equipment and components in a configuration that precludes the occurrence of a large leak event and the ***hazard*** potential it may cause.

2.5.4 Fuel Delivery and Storage System Operation

The following safe operating practices related to the 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 storage vessels in the ***fuel storage system*** should be isolated.

- **Bus Fueling.** A bus engine ignition cut off 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.

- **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 ***LP-Gas*** in any one system and help prevent a large leak event. Complying with the requirements of NFPA 58, §8-2.4(d) will automatically achieve this.

2.5.5 Detection and 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 ***LP-Gas*** or the heat rise from an on-board fire and will suppress that fire with a dry chemical extinguisher. There are systems 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. These systems can be used 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.

2.5.6 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 a *LPG*-powered bus is brought into the maintenance facility for repair, the battery disconnect switch, if available, should be set to the "off" position. This should be effected prior to initiating any work on the bus.

- For major repairs, each available manual shut-off valve on the fuel delivery system should be (manually) closed. This includes the shut-off valve on the tank.

- 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*** (high pressure), then the fuel in the ***fuel storage system*** and throughout the fuel delivery system should be depleted. ***Defueling*** procedures are discussed in the next section.

CAUTION

If the *LP-Gas* fuel delivery or storage system has failed and *LP-Gas* is escaping, the leaking system should be isolated by manually closing adjoining valves. A BUS LEAKING *LP-Gas* 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.

2.5.7 Defueling Strategy

When it is necessary to defuel a bus due to scheduled maintenance (hot work), replacement of one or more pressure components, or due to an ***LP-Gas*** leak, the following procedure can be used and incorporated into existing maintenance procedures. It is suggested that transit agencies using LP-Gas explore a system for ***defueling*** a bus.

2.5.7.1 Precautions

The following precautions should be observed when a bus is to be defueled:

CAUTION

1. ***Defueling*** **must 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 *LPG* from a bus fuel delivery and storage system and when *LP-Gas* may be intentionally vented into the atmosphere. It is of paramount importance to properly and adequately electrically ground any tubing or storage system during urgent *LPG defueling* to atmosphere.**

3. **Improper *defueling* of *LPG* to the atmosphere can ignite the *LP-Gas* fuel in the case of improper electrical ground. This ignition could be caused by the static electric charges that build as the *LPG* rushes through the restrictive opening of the tubing or storage system during atmospheric *defueling*.**

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

It is not possible to defuel a bus through the fill port because of the existence of a check valve on the bus side of the fuel system. Furthermore, if atmospheric venting is required, a special vent pipe system must also be installed at the facility. (This vent pipe system is discussed later in this section.)

2.5.7.2 Scheduled Defueling Sequence

The following sequence can be considered for ***scheduled defueling***:

- Move the bus to a pre-designated, safe, and convenient location for ***defueling***, (i.e. where the ***defueling*** apparatus is located).

- Prepare for ***defueling*** by consuming as much of the ***LPG*** fuel that is contained in the bus fuel delivery system as possible. This is accomplished by closing either the manual valve on each of the bus storage vessels or the electric solenoid valves and running the bus's engine until the ***LPG*** remaining in the fuel delivery system is no longer capable of operating the engine. Refer to Section 2.5.7.3, "Run-down Procedure," for additional details.

- Start the ***defueling*** procedure by employing either the vent-back procedure, additional bus procedure or compressor inlet procedure, all of which are further described below.

- Finally, in order to reduce the ***residual LP-Gas*** from the bus fuel delivery and storage system to atmospheric pressure, employ the atmospheric venting procedure included in Section 2.5.7.6.

2.5.7.3 Run-down Procedure (Preparing for *defueling*)

In this strategy, the bus engine is operated with the storage system valves closed until the fuel delivery system is mostly depleted of ***LP-Gas***. This can be accomplished as follows:

1. Close the manual shut-off valve on each storage vessel or close the electrically activated solenoid valves on the fuel delivery and storage system.

2. Run the bus on ***LPG*** until it stalls.

3. Attempt to start the bus again. If it starts, let it run until it stalls again. Repeat this step until the bus no longer starts.

4. If it is planned to remove one or more storage vessels containing ***LPG*** from the bus and transport it to another location, then the storage vessel must be labeled as containing ***LPG***, tightly fastened to the transport vehicle, electrically grounded at all times, and transported according to all applicable DOT requirements.

CAUTION

The storage vessel must be electrically grounded before the fuel line tubing is disconnected from the valve and the storage vessel is removed from the vehicle. If further venting is to occur after removal from the bus, then the storage vessel should also be grounded until after all venting is completed. If the storage vessel is to be transported containing *LPG* then it should be properly labeled, fastened and grounded to the vehicle while in transportation.

2.5.7.4 Additional Vehicle Procedure (*defueling* to Another *LPG* Bus)

This strategy requires the use of additional buses to accept the ***LPG*** from the bus to be defueled. This procedure is possible only when an ***LPG*** transfer pump is available and vapor return connections between the two bus tanks are possible.

The following issues should be noted regarding this type of procedure:

- Run-down procedure (indicated in Section 2.5.7.3) should be performed prior to performing this procedure.
- All of the buses used in this procedure must have an on-board ***defueling*** connection in the ***fuel storage system***, including vapor return lines.
- The hoses used for ***defueling*** must conform to the requirement of NFPA 58 §8-2.5(d).
- The buses should be electrically grounded or electrically connected to each other.
- All safety precautions should be observed to ensure that there are no gas leaks during the transfer process.
- It should be ensured that no air enters the ***LPG*** tank that is being defueled. Where available, a propane vapor should be used to provide the driving potential to off load the liquid in the tank. When all liquid has been transferred, the compressor control valves should be realigned and draw vapor from the tank being emptied to reduce the pressure in the container to about 20-30 psig, prior to the flaring of the remaining product to reduce the tank pressure to atmospheric.
- High pressure nitrogen could be used to purge the tank under extreme circumstances to induce liquid flow to another tank (in lieu of a transfer pump). Condensable gas, such as nitrogen, can cause the pressure relief valve to open prematurely during or following filling the container.

2.5.7.5 Urgent Defueling

There may arise emergency situations in which there is a need to remove the ***LPG*** from the bus immediately and it is therefore not feasible to follow any of the above strategies. Such a situation can be defined as "urgent." The discovery of a continuous leak from the high pressure side of the fuel delivery or storage system is an example of this situation. An ***urgent defueling*** can be performed with the atmospheric venting procedure described below. **Only in an urgent situation or emergency condition[5] should *LPG* be vented directly to the atmosphere.**

2.5.7.6 Atmospheric Venting

If conditions are such that the venting to the atmosphere can be accomplished safely, the option of burning the released gas can be considered if the requirements of NFPA 58 §4-3.2.1(c) are satisfied. These conditions include controlled burning, flame being at least 7.6 m (25 feet) from combustibles or a hazardous atmosphere.

It should be the transit agency's policy to restrict the *defueling* of *LPG* into the atmosphere to urgent or emergency situations or to purge *residual* *LPG* only. Furthermore, each agency should strongly urge minimizing, to all practical extent, the quantity of ***LPG*** released to the atmosphere for safety, environmental, and other reasons.

2.6 PERSONNEL TRAINING

The safe operation of any ***LPG*** bus transit facility will depend 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 the ***LPG*** buses.

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[5]An "urgent situation" or "emergency condition" is one in which a major release is about to occur, which condition may pose immediate threat to life and property. The gas discharge to the environment, under the emergency condition, does not require any prior permission from U.S. EPA, but may come within the purview of accidental release notification requirements.

The training should be based on the function and level of responsibility. The following individuals (at a minimum) should be provided with formalized and appropriate training.

- Fuelers
- Bus Operators
- Mechanics
- Supervisors
- Management
- Other Building Occupants

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 2-3 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 ***LPG*** use will be similar to that which is required for other fuels.

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

Training in all areas identified in Table 2-3 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 Federal Transit Administration offers one such course entitled "Instructor's Course in Alternative Fuel Safety." 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 the transit agency.

Table 2-3
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

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

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.

Fire drills should be conducted on a regular basis and records kept and be 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 the 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.

Personnel required to receive safety training on the chemical/physical properties of ***LPG*** should receive basic information as to make them aware of the potential dangers associated with a release of the gas. The information contained in Section 2.1 "General Properties" of this document should be included in the training.

Fire prevention should be practiced whether or not ***LPG*** buses are used. Good housekeeping and the proper storage of flammable and combustible materials is essential in order to provide for a safe workplace for the employees. When ***LPG*** 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 to contributing to the elimination of the potential for a problem.

Some jurisdictions may require special licenses or permits from the fire department to operate ***LPG*** 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 ***LPG*** and/or the ***LPG*** 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 safety management in a facility handling/storing/or dispensing a hazardous/flammable material such as ***LPG***. The Emergency Response Action Plan must 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 these plans.

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 in the plan as a minimum, of the following items:

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 ***LPG*** 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 must be 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 ***LPG*** facility, local civic groups, school boards, and local businesses should be made aware of any emergency action plans which could effect 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 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 modifications 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.
- 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*** analyses 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***.
- 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 ***hazard***s 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 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 (Table 3-1, Table 3-2, and Table 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
(dark shading)	IIIB, IIC, ID	Undesirable (allowable with agreement from Authority having jurisdiction)
(no shading)	IVA, IVB, IIIC, IID, IIID, IE, IIE	Acceptable with notification to the Authority having jurisdiction
(hatched)	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 Table 3-1, Table 3-2, and Table 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) involves 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

Autoignition Temperature The temperature at which a flammable concentration of vapor will ignite in the absence of an external ignition source. (Ignition effected by a hot surface rather than by an open flame or a spark.)

Boiling Liquid Expanding Vapor Explosion (BLEVE) A phenomenon that is caused by a long duration exposure of an LPG fuel tank to an external fire resulting in the tank failure. The suddenly depressurized, hot, liquid evaporates producing a large quantity of vapor in a very short time which gets ignited by the fire forming a large fireball.

Chemical Formula The chemical composition. Methanol and ethanol are pure substances with a definite formula. Natural gas, commercial propane, gasoline, and diesel fuel have variable compositions.

CNG (Compressed Natural Gas) 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 compressed natural gas.

Controls Most modern transit LPG 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 control the starting and stopping of the compressors as well as opening and closing a number of control valves which are used to control flow of liquefied gas between various station components.

Defueling This is defined as removing all of the LPG inventory from a bus fuel delivery and storage system by allowing contained LPG to flow to another tank.

Detonation The very rapid burning of vapor resulting in a self-sustaining shock wave, the pressure behind which is several atmospheres. Detonation waves travel at speeds exceeding the speed of sound in air.

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

Diesel Volume Equivalent (DVE) The number of standard cubic meter of LPG equivalent to a liter of diesel (or, alternatively, SCF of natural gas equivalent to a gallon of diesel on an energy equivalent basis).

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.

Flame Temperature The temperature of a flame burning a stoichiometric mixture (neither fuel nor air is in excess) of fuel and air.

Flammability Limits The range of fuel vapors 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.

Fuel Storage System Shall be defined as one or more containers, including their interconnecting equipment, that are designed, fabricated and approved for use in the mobile containment of LPG for bus power.

Fuel Tank A LPG container on board the vehicle.

Gas Dispensers The gas dispensers often look and function much like a diesel dispenser. LPG is a sealed system that requires no venting during a normal fill cycle.

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 (say, a kilogram) of liquid fuel. For comparison, the latent heat of vaporization of water is 2550 kJ/kg.

High Release Rate Event (HRE) This is characterized by LPG release due to a catastrophic failure in the high pressure tubing connecting the bank of fuel storage cylinders (fuel tanks) or a gas discharge through a pressure relief device (either due to malfunction, a thermal fusible plug failure, or tank overpressure). This type of leak would lead to the release of a large volume of gas which may pose a hazard if released inside a building.

Hydrocarbon Gas Any gas which contains both carbon and hydrogen in its molecular structure. A saturated hydrocarbon is represented by the chemical formula C_nH_{2n+2}. Propane (C_3H_8) is a saturated hydrocarbon.

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.

Low Release Rate Event (LRE) Natural gas released from a LPG fueled bus is characterized as a "low release rate event" if the gas is emanating from a loose fitting, a valve stem, a crack in the gasket, etc. This type of leak can be expected to dissipate rapidly and not pose significant hazard, either immediately or over an extended period of time. It is assumed that the total volume of gas leaked during the leak event is considerably smaller than the volume of the building into which the leak occurs. The air currents induced by the normal ventilation should be adequate to dissipate the vapors below the flammable limit quickly.

***Liquefied Petroleum Gas (LPG)** A gas that at normal temperature and pressure consists of mainly propane, with smaller amounts of propylene, butane, and other light hydrocarbons. Liquefication is achieved by applying pressure at ambient temperature.

***LP-Gas** The vapor generated by the evaporation of LPG.

MTBE Mean time between events.

MTBHE Mean time between hazardous events = mean time between the occurrence of critical or catastrophic hazards (Table 3-1).

Pressure Relief Device (PRD) A safety device provided in the high pressure gas line very close to the tank to vent excess pressure in the tank in case of tank overpressure. The device is actuated by either overpressure or high tank temperature. The excess pressure in the tank is relieved by venting the contents of the tank to the atmosphere.

Relative Fuel Vapor Density The density of the fuel vapor compared to 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.

Saturated Hydrocarbon A chemical molecule containing carbon and hydrogen atoms in a combination represented by C_nH_{2n+2}. Methane, ethane, propane, butane, pentane, hexane, heptane, are examples of a saturated hydrocarbon.

Scheduled Defueling The planned removal of LPG from a bus fuel delivery and storage system in order to make repairs or modifications to the bus equipment.

Stoichiometric Air/Fuel Ratio The mass of air that is just enough to burn a unit mass of fuel. A stoichiometric ratio of 15.6 implies that one kg of fuel requires 15.6 kg of air for complete combustion if neither fuel nor air is to be in excess.

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 Flammable 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.

Urgent Defueling The immediate, unplanned removal of LPG from a bus delivery and storage system to prevent an impending hazard to persons and/or property.

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/@ for the fuel to the lower heating value of gasoline or diesel fuel in MJ/@.

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.

* Per definition in NFPA 58.

List of Acronyms

A&E	Architectural and Engineering
ACH	Air Changes per Hour
ADA	Americans with Disabilities Act, 1990
AFI	Alternative Fuels Initiative (of U.S. DOT/FTA)
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
BLEVE	Boiling Liquid Expanding Vapor Explosion
BOCA	Building Officials and Code Administrators (Chicago, IL)
CFR	Code of Federal Regulations
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 the U.S. DOT
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
NPGA	National Propane Gas 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
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
TMS	Technology & Management Systems, Inc.
U.S. DOT	United States Department of Transportation
UFC	Uniform Fire Code
UFL	Upper Flammability Limit
UL	Underwriters Laboratories
Volpe Center	Volpe National Transportation Systems Center, U.S. DOT, Cambridge, MA

Glossary of Graphic Symbols

CAUTION — Caution

OSHA — Occupational Safety & Health Administration Logo

National Electrical Code Logo

NFPA® — National Fire Protection Association Logo

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