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

# Clean Air Program

## Design Guidelines for Bus Transit Systems Using Compressed Natural Gas as an Alternative Fuel

June 1996
Final Report
Reprint
August 1997

OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION

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13. ABSTRACT (Maximum 200 words)

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

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

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

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

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# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC / METRIC TO ENGLISH

### LENGTH (APPROXIMATE)

**English to Metric**

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

**Metric to English**

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

### AREA (APPROXIMATE)

**English to Metric**

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

**Metric to English**

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

### MASS – WEIGHT (APPROXIMATE)

**English to Metric**

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

**Metric to English** (MASS - WEIGHT (APPROXIMATE))

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

### VOLUME (APPROXIMATE)

**English to Metric**

| | | |
|---|---|---|
| 1 teaspoon (tsp) | = | 5 milliliters (ml) |
| 1 tablespoon (tbsp) | = | 15 milliliters (ml) |
| 1 fluid ounce (fl oz) | = | 30 milliliters (ml) |
| 1 cup (c) | = | 0.24 liter (I) |
| 1 pint (pt) | = | 0.47 liter (I) |
| 1 quart (qt) | = | 0.96 liter (I) |
| 1 gallon (gal) | = | 3.8 liters (I) |
| 1 cubic foot (cu ft, ft3) | = | 0.03 cubic meter ($m^3$) |
| 1 cubic yard (cu yd, yd3) | = | 0.76 cubic meter ($m^3$) |

**Metric to English**

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

### TEMPERATURE (EXACT)

**English to Metric**

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

**Metric to English**

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

### Pressure (EXACT)

**English to Metric**

| | | |
|---|---|---|
| 1 psi | = | 6.8948 k Pa |

**Metric to English**

| | | |
|---|---|---|
| 1 M Pa | = | 145.04 psi |

### ENERGY & ENERGY DENSITY (EXACT)

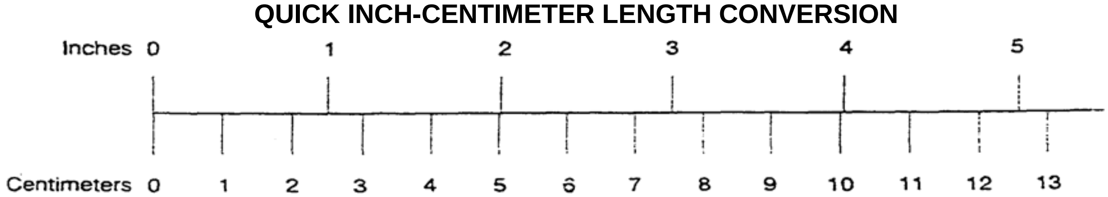
**English to Metric**

| | | |
|---|---|---|
| 1 Btu | = | 1.05506 kJ |
| I Btu/lb | = | 2.326 kJ/kg |

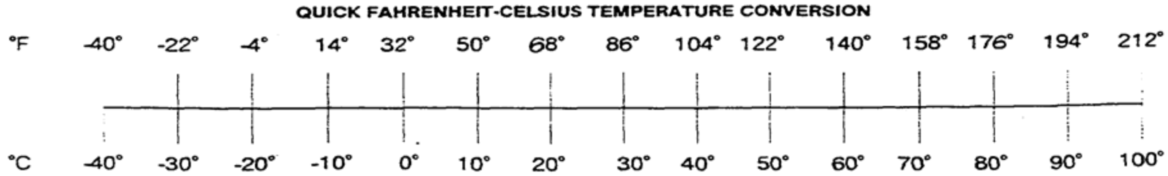
**Metric to English**

| | | |
|---|---|---|
| I MJ | = | 947.81 Bru |
| 1 MJ/kg | = | 430 Btu/lb |

## QUICK INCH-CENTIMETER LENGTH CONVERSION




QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



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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. Safety is one of the key issues in the use of alternative fuels both in operation and servicing of transit buses. However, at present, there are no comprehensive guidelines for the safe design and operation of alternative fuel facilities and vehicles for transit systems to follow in either retrofit or new facility designs. The Federal Transit Administration (FTA) has therefore initiated the development of "Design Guidelines for Transit Bus Facilities Using Alternative Fuels."

This report provides design guidelines for the safe use of Compressed Natural Gas (CNG). It forms a part of the series of individual monographs being published by the FTA providing guidelines for the safe use of 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 petroleum fuel with alternative 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 statutes 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 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 CNG 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.

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

[(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, LPG, LNG, and Methanol/Ethanol.

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 are 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 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 three organizations: the U.S. Department of Transportation (DOT); the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA); and the National Fire Protection Association (NFPA). Their logos appear in the list of graphic symbols, at the end of this document, as does the logo for the National Electrical Code, which appears in NFPA 70.

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

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

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

**Units of Measure** These are expressed in Standard International (SI) units (e.g., meters, kilograms, seconds, and Kelvin). The equivalent in British units, where different from SI, is provided in parentheses. Units of measure appearing in a quotation are reprinted exactly as they appear in the quoted passage.

## 1.4 LIST OF STATUTES, REGULATIONS AND STANDARDS

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

### *1.4.1 Statutes*

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

### *1.4.2 Regulations*

Copies of the following regulations can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 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 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 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
# Issues and Practices Related to CNG

## 2.1 GENERAL PROPERTIES

### *2.1.1 Physical Properties*

Methane ($CH_4$) is the principal constituent of ***natural gas***, with other higher hydrocarbons present in very low concentrations. The composition of methane and other constituents of pipeline ***natural gas*** may vary both geographically and seasonally. A range of pipeline gas compositions is shown in Table 2-1. Methane gas is colorless, odorless, and tasteless. To help detect leaks of this gas from storage ***containers*** and piping, an odorant (such as mercaptan) is mixed at very low concentrations.(2) An average person can detect an odorized gas at about 1 % gas concentration in air. U.S. DOT regulations (49 CFR, Section 192.625) require that a "combustible gas in a distribution line should be odorized so that at a concentration in air of one-fifth of the lower explosive limit, the gas is readily detectable by a person with a normal sense of smell." Prolonged exposure to smell of the odorant may result in diminished sensitivity of the person exposed to the smell.

***Natural gas***, at ordinary temperature and atmospheric pressure, is in a gaseous state and has a density of about 55% that of air at the same condition. Because of its low energy density, the gas is compressed to increase the amount of fuel (mass) that can be stored at room temperature in a specified volume (hence the term Compressed Natural Gas or ***CNG***). The pressures at which ***CNG*** is held in storage in a transit agency or in bus ***fuel tanks*** are high; 16.7 M Pa to 31.1 M Pa (2,400 to 4,500 psig). As a result of these high storage pressures, about 300 times more gas by mass can be stored than can be stored in the same volume at atmospheric pressure(3) Table 2-2 shows some of the important properties of methane. The same values may also be used for ***CNG*** vapors under most circumstances.

---

(2) In the range of 3.5 mg/m$^3$ (0.2 lbs./million cubic feet) to 10 mg/m$^3$ (0.45 lbs./million cubic feet).

(3) At 20 °C (68 °F), the gas density, as a ratio of ambient air density, ranges from about 110 to 165.

**Table 2-1**
**Range of Concentrations of Pipeline *Natural Gas***

| Chemical Specie | Formula | Range of Pipeline Gas Concentrations with Low and High Methane Contents* | |
|---|---|---|---|
| Methane | $CH_4$ | 82.50† | 96.80‡ |
| Ethane | $C_2H_6$ | 6.90 | 1.50 |
| Propane | $C_3H_8$ | 1.00 | 0.20 |
| Butane | $C_4H_{10}$ | 0.20 | 0.10 |
| Pentane | $C_5H_{12}$ | 0.10 | 0.00 |
| Hexane | $C_6H_{14}$ | 0.00 | 0.10 |
| Heptane | $C_7H_{16}$ | 0.00 | 0.00 |
| Oxygen | $O_2$ | 1.50 | 0.00 |
| Carbon Dioxide + Nitrogen | $CO_2$. $N_2$ | 7.80 | 1.30 |
| TOTAL | | 100.00 | 100.00 |

*Data from GRI Publication (Liss et al. 1992)
†Mean Values for Colorado
‡Mean Values for Georgia

**Note: *Natural gas*** compositions vary geographically. The fuel supplier should be consulted for gas quality information. The transit agency must ensure that the bus engine manufacturer's fuel specifications and the composition of pipeline gas supplied by the local gas utility agree. Recommended fuel specifications and limits on various specie composition in ***natural gas*** are indicated in SAE Publication No. J1616 (see February 1994 version) published by SAE International (formerly the Society of Automotive Engineers of U.S.) and NFPA 52.

## Table 2-2
## Important Properties of Methane[†]

| Property | Units | Value |
|---|---|---|
| Density of Gas at 20 °C | | |
| – At Ambient Pressure | $kg/m^3$ | 0.65 |
| | lb/cft | 0.041 |
| – At a High Pressure | $kg/m^3$ | 189.0 at 25 M Pa |
| | lb/cft | 11.8[-] at 3,625 psig |
| Temperature at Which the Density of Atmospheric Pressure Vapor ***CNG*** Is the Same as That of Air at Normal Temperature and Pressure | K | 172" |
| | °F | -150 |
| Molecular Weight | kg/kmole | 16.043 |
| Flammability Range in Air | volume % | 5.3 to 15 |
| Minimum Energy for Ignition in Air | mJ | 0.29 |
| Ignition Temperature in Air ***(Autoignition Temperature)*** | K<br>°F | 813<br>1,003 |
| Heat of Combustion (Lower Heating Value) | MJ/kg | 50[‡] |
| | Btu/lb | 21,505 |

[†] Pure methane properties are indicated in the table because methane is the principal constituent of CNG. Therefore, some values can be used for-CNG also.

All property values, except if otherwise identified, are from a National Bureau of Standards Publication (Hord, 1976).

[-] From the data in American Heating, Refrigeration, and Air Conditioning Engineer's (ASHRAE) Handbook (ASHRAE, 1969).

[--] Density of ambient air at 20 °C is 1.2 $kg/m^3$.

[‡] ***Natural gas*** heating value may be lower than that indicated for methane by as much as 4 to 5 MJ/kg.

### *2.1.2 Flammability and Associated Hazards*

***Natural gas*** is flammable in air. It can be ignited by an open flame, an electrical spark (of energy above the minimum ignition energy), or a very hot surface, if the concentration of ***natural gas*** in air is between the flammability concentrations (see Table 2-2). Even a weak spark due to static electricity discharge could be sufficient to ignite a flammable concentration of ***natural gas***-air mixture. However, ignition by a hot surface will require a sufficiently high temperature, greater than 813 K (1003 °F).

A gas pocket or cloud having a concentration of ***natural gas*** in air outside the flammability concentration range will not ignite. The ***Upper Flammability Limit*** (UFL) is 15% ***natural gas*** and the ***Lower Flammability Limit*** (LFL) is 5% ***natural gas*** concentration in air. In the case of ***CNG*** releases from a ***fuel tank***, the gas concentration close to the release location is expected to be high (and possibly higher than the UFL over a substantial volume of the cloud near the source). This **does not,** however, mean that the high concentration cloud will not bum. This is because even high ***natural gas*** concentration clouds have pockets of gas at the cloud edges which have flammable concentrations; should ignition sources be present within these "flammable gas pockets," ignition of the cloud is possible. Once ignited, the dynamics of air movement will ensure that the cloud will be burned.

If the gas is confined and ignited, a localized increase in pressure will result. Depending on the degree of confinement, mass of vapor ignited, and other geometrical parameters, such an ignition may result in an over pressure that can cause damage to structures over distances of several meters. Ignition of a mixture of air and ***natural gas*** in confined spaces (such as pits, ceiling pockets, and sewer lines) may result in a ***detonation***. The consequence of this is the formation of a blast wave capable of causing significant structural damage and human (blast) injury over large distances. However, under the normal open conditions that exist in a bus facility, the occurrence of a ***natural gas***-induced ***detonation*** can be considered to be improbable to remote.

### *2.1.3 High Pressure Gas Release: Behavior and Hazards*

If there is a leak from the high pressure side of the fuel system, a high velocity (and high momentum) cold gas jet will result.[(4)] Therefore, the gas density at the point of release could be higher than that of air. However, the high momentum jet will flow in the direction of release, perhaps for a distance of several meters, along the orientation of jet axis unless the jet impinges on solid objects or a wall. Outside air mixes with the gas jet and lowers the ***natural gas*** concentration; the farther the jet travels the lower will be the gas concentration.

The ***natural gas*** concentration decreases from the centerline of the jet outward (radially). The gas concentration at the core will be high close to the release point. However, the concentration on the jet centerline decreases as the distance from the release point increases. Even in regions where the gas concentration in the jet core is higher than the ***upper flammability limit***, there will exist a region on the jet periphery where gas concentrations will be in the flammable range. The

[(4)] Because of the significant pressure range over which the expansion of the gas occurs from the high pressure to atmospheric pressure the temperature of the gas jet at exit will be very low, 112 K to 190 K (-260 °F to -118 °F).

dilution of the jet with air mixing results in the reduction in the jet velocity as well as the density of the gas. As the distance from the release point increases, the gas density in the jet will become closer to that of the surrounding ambient air. When the jet velocity is small, the subsequent movement of the gas plume will be influenced by air currents within the building induced by the ventilation flow, or by hot surfaces. In other words, the initial jet has no effect on the later movements of the gas inside the building when the gas density is close to that of the surrounding air.

Hazards that may result from a high pressure ***CNG*** jet include:

- Injury from small particles and floor debris aerosolized by the jet.

- Human injury from high jet momentum or exposure to very cold gas near the release point.

- Ignition of the jet by a static discharge between the jet and the leak source. Ignition of a high velocity ***CNG*** jet will result in a jet fire (also called a "torch fire") which can be at high temperature (1,150 K to 1,250 K or 1,600 °F to 1,800 °F). Such a torch fire impinging on a person can cause serious burns within seconds, and can cause damage to structural elements.

- High intensity noise from the high velocity jet.

A high rate ***CNG*** release event (such as from a severed high pressure fuel line) under the bus chassis will initially tend to stay close to the ground until sufficient heat from the ground and other objects is imparted to the gas to make the cloud buoyant. The released gas may fill the pit under a bus. While ***natural gas*** is non-toxic it can displace air in a pit or reduce oxygen concentration levels that can potentially cause asphyxiation of workers in the pit. Also, any gas trapped in the pit or in pockets in the ceiling of a building can pose potential ignition and explosion hazards.

Tanks containing ***CNG*** should be anchored at all times to prevent rocketing if a failure occurs (such as a valve stem break).

***For additional information on CNG properties, safety precautions, and procedures, the following technical reference(s) should be reviewed/ consulted:***

*"Compressed Natural Gas Fuel Use Training Manual." Report No. FTA-OH-06-0060-92-3. Published by Federal Transit Administration, Office of Technical Assistance, Washington, DC 20590. September 1992.*

*"Properties of Alternate Fuels." Report No. FTA-OH-06-0060-94-1. Published by Federal Transit Administration, Office of Technical Assistance, Washington, DC 20590. March 1994.*

### *2.1.4 Fuel Economy and Diesel Equivalence*

Large quantity storage *of* ***CNG*** at a bus fueling station is not cost-effective. In addition, even at high pressure (25 M Pa or 3,600 psig), the gas density is only about 20% that of diesel, hence requiring, at the very minimum, about five times more storage tank volume than for an equivalent quantity of diesel storage. Therefore, in a majority of transit facilities using ***CNG,*** ***natural gas*** delivered at pipeline pressure is compressed on site and the buses are fueled at the same time.

Table 2-3 shows a comparison of energy equivalent volumes between ***CNG*** and diesel. The information provided in this table is useful in sizing the fueling station for a given fleet of buses and their duty cycle.

### *2.1.5 Natural Gas Supply Quality*

The quality of pipeline ***natural gas***, in terms of the methane content, can vary as shown in Table 2-4. If propane is blended (as in peak shaving applications) with the pipeline gas, the lowest ***natural gas*** concentration can be as low as 55.8%. In certain areas where the gas utility blends refinery stack gas into the pipeline gas, ***natural gas*** content can vary daily (and in certain cases by the hour).

**Table 2-3**
**Diesel Equivalent Values**

**1. LOWER HEATING VALUES**

| 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 Natural Gas (LNG) | 20,904 | $MJ/m^3$ | 75,000 | Btu/gal |
| Compressed Natural Gas (CNG) | 36.15 | $MJ/m^3$ (std) | 970 | Btu/SCF |

**2. DIESEL EQUIVALENT VOLUMES FOR CNG**

| Parameter | SI Units | | Conventional Units | |
|---|---|---|---|---|
| | Value | Units | Value | Units |
| DVE#1† | 0.9726 | $m^3$ (std)/liter | 130 | SCF/gal |
| DVE #2‡ | 1.0025 | $m^3$ (std)/liter | 134 | SCF/gal |
| 500 liters of #1 diesel | 540* | $m^3$ (std) of NG | — | — |
| 125 gallons of #1 diesel | — | — | 18,000* | SCF of NG |

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

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

**Table 2-4**
**Weighted U.S. National Statistics for Pipeline Natural Gas Component Concentrations in 26 Major Urban Areas**

| Chemical Specie | Chemical Formula | Range of Concentrations* (Volume %) Without Propane Blending | | | |
|---|---|---|---|---|---|
| | | Minimum | 10th Percentile | 90th Percentile | Maximum |
| ***Natural Gas*** | $CH_4$ | 74.5 | 89.6 | 96.5 | 98.1 |
| Ethane | $C_2H_6$ | 0.5 | 1.5 | 4.8 | 13.3 |
| Propane | $C_3H_8$ | 0.0 | 0.2 | 1.2 | 23.7 |
| Higher Hydro-carbons | | 0 | 0.1 | 0.6 | 2.1 |
| *Butane* | $C_4H_{10}$ | | | | |
| *Pentane* | $O_5H_{12}$ | | | | |
| *Hexane* | $C_6H_{14}$ | | | | |
| *Heptane* | $C_7H_{16}$ | | | | |
| Carbon Dioxide + Nitrogen | $CO_2 + N_2$ | 0.0 | 1.0 | 4.3 | 15.1 |

*Data from Liss et al. 1992

**Note:** The percentages do not add up to 100 because each row indicates the minimum and maximum concentration of individual components in sampled ***natural gas.***

Also note that the data in Table 2-1 show the mean values over a region over a long period of time. The data in this table represent national data statistics.

A transit agency desiring to use ***CNG*** fuel in buses should be cognizant of this possibility and in conjunction with the engine supplier enter into discussions with its supplier gas utility and ensure acceptable gas quality. Table 2-4 shows the lowest and highest concentrations of the individual constituents observed in pipeline ***natural gas***, using the statistics of 26 major U.S. cities (Liss, et al. 1992). Also indicated are the 10th and 90th percentile values. Table 2-5 shows the minimum gas quality recommended by two major engine manufacturers for use in ***natural gas*** fueled bus engines.


**Low *natural gas* content (and the corresponding higher concentrations of higher hydrocarbons) leads to an increased heating value for the gas. Premature engine damage can occur if gas quality is not within specification.**

At a transit agency site, every effort should be made to remove most of the water content from the gas before supplying to the compressor. In general, the concentration of sulphur in "sweet"[5] ***natural gas*** is very low (from the odorant) to nonexistent. Corrosion created tank damage can occur by the acidity resulting from the combination of sulphur and water.

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[5] When hydrogen sulphide is removed from the well head ***natural gas,*** the gas is said to be "sweet."

## Table 2-5
## Sample Fuel Quality Compositions Recommended for Use in Natural Gas Fueled Engines

| Property | Limit Values By | | ASTM Test Method |
|---|---|---|---|
| | Detroit Diesel Corp. | Cummins Engine Co. | |
| Hydrocarbon | Mole percent | | |
| Methane | 88% min. | 90% min. | D1945 |
| Ethane | 6% max. | 4% max. | D1945 |
| Propane | 1.7% max. | 1.7% max. | D1945 |
| Other | | | |
| C4 and Higher | 0.3% max. | 0.7% max. | D1945 |
| Other Gaseous Species | Mole percent | | |
| Hydrogen | 0.1% max. | 0.1% max. | D2650 |
| Carbon Dioxide + Nitrogen + Oxygen | 4.5% max. | 0.5% max. | D1945 |
| Carbon Monoxide | 0.1% max. | 0.1% max. | D2650 |
| Other Species | | | |
| Methanol | 0% max | — | No Test Method |
| Sulfur, Total | 22 ppm/v | 0.001 % max. †† | D 4468 |
| Performance Related Properties | | | * |
| Motor Octane Number | 115 min | | D 2623 |
| Wobbe Number | 1290-1380 BTU/$ft^3$ | 1300-1377 BTU/$ft^3$ | D3588 |
| Contaminants | ** | ** | |
| Pressure Water Dew Point Temperature, Max. | † | — | D 1142 |
| Pressure Hydrocarbon Dew Point Temperature, Max. | † Below which will form 1 % condensate | — | D 1142 |
| Odorant | ‡ | — | |

* Test method D 2623 was obsoleted by ASTM in 1991. Wobbe Index (WI), also known as Wobbe Number, is a measure of fuel energy flow rate through a fixed orifice under given inlet conditions. Numerically, WI = (dry, higher heating value in BTU/$ft^3$)/(specific gravity)$^{1/2}$.

** The compressed ***natural gas*** shall not contain dust, sand, dirt, gums, oils, methanol, or other substances in an amount sufficient to be injurious to the fuel station equipment or the vehicle being fueled.

† The dew point at vehicle fuel storage ***container*** pressure shall be at least 10 °F (5.6 °C) below the 99.0% winter design temperature listed in Chapter 24, Table 1, Climatic Conditions for the United States, in *American Society of Heating, Refrigerating and Air Conditioning Engineer's (ASHRAE) Handbook,* 1989 fundamentals volume. Testing for water vapor shall be in accordance with ASTM D 1142, utilizing the Bureau of Mines apparatus.

‡ The ***natural gas*** at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air of 1 % by volume.

†† Cummins' specification is based on Title 17 CCR, Section 94112, Method 16.

## 2.2 FUELING FACILITIES

The physical and operational requirements of a ***CNG*** fueling facility are discussed in this Section. A fueling facility consists of the ***gas dryer***(s), gas ***compressors, gas storage*** ("buffer storage"), control systems, ***gas dispensers***, as well as the area (or room) in which the actual fueling of buses takes place. As a general rule, the fueling facility can be divided into two principal areas, namely, the equipment area (in which ***gas dryers, compressors***, storage vessels, and valving and control are located) and the fuel dispensing area. A fueling facility may be indoor(6) or outdoors. A majority of the currently operating ***CNG*** fueling facilities have the equipment outdoors with fueling being indoors or outdoors.

The general governing standard for the design of fueling facilities is NFPA 52 or the Uniform Fire Code. The Uniform Fire Code closely resembles NFPA 52. Some differences, however, do exist, making it necessary to consult the standard which is mandated in the area of the project. Several local or state regulations also take precedence over NFPA 52 and model fire codes such as the Uniform Fire Code (UFC), Building Officials and Code Administrators (BOCA) fire code, Southern Building Code Congress International (SBCCI), etc. These include the New York City Fire Department 3RCNY 9-30-92, Chapter 23-01; California Code of Regulations Title 8 Industrial Relations; and the Railroad Commission of Texas Regulations for Compressed ***natural gas***. There may be additional local or state standards which regulate the construction on a given project. Thus, it is critical that these standards are identified and followed and it is advisable that the regulatory agencies involved are consulted early in the design phase. In some instances, the building and fire insurance companies may impose additional standards. A transit agency should consult with its insurance carrier and determine which codes are necessary for compliance.

### *2.2.1 Compression Area*

The equipment in this area generally occupies between 200 $m^2$ and 500 $m^2$ (approximately 2,000 to 5,000 square feet) including separations around individual machines. The size of this area depends of course on such factors as the bus throughput, fuel per bus, inlet gas pressure and the regulatory and practical separation requirements.(7)

The general standard governing this area is NFPA 52, ***Compressed Natural Gas (CNG)*** Vehicular Fuel Systems (1995), as well as the other regulations discussed previously. These regulations specify the electrical, piping and vessel codes that apply to this equipment. The regulations also specify the location and level of the electrically hazardous areas surrounding the equipment, as well as defining separations between ***CNG*** equipment and other buildings, railways, property lines, sources of ignition and other equipment and obstructions.

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(6) The expression "indoor facility" should be construed to mean the situation where the conditions for "outdoor" are not met. See Section 2.2.2.1 of this report.

(7) A typical 360 $m^3$/hr (= 200 scfm) facility will require about 40 $m^2$ (= 400 sq. ft.) for the compressor, 20 $m^2$ for the fuel storage, and 10 $m^2$ for fuel metering and dehydration equipment. A 2100 $m^3$/hr (1200 scfm) station which represents the requirements for a 200 bus fleet may require a 80 $m^2$ compressor area, 20 $m^2$ for fuel storage, and 20 $m^2$ for dehydration equipment.

The above designations allow the siting of ***CNG*** equipment within a new or existing ***CNG*** bus facility. It is general practice for the compression equipment to be located either in its own pre-engineered enclosure(s) or for a dedicated outbuilding to be constructed to house some or all of this equipment. The compression equipment can thus be separated from the existing garage and therefore not impose any hazardous area requirements on the existing facility. However, NFPA 52 does not prohibit the siting of equipment within a facility or on the roof of the facility provided that ventilation, deflagration venting, and electrical area classification requirements are in compliance.

There are many non-regulated issues associated with the proper design of a ***CNG*** fueling system. For example, it is highly desirable to provide some level of redundancy in the compression, drying and dispensing equipment to accommodate a planned or unplanned shutdown of equipment.

In addition to NFPA 52 and the other similar standards which primarily deal with siting issues, new standards are currently being drafted to address the ***compressor*** package, as well as components such as hoses, hose breakaway and valves.[8]

### *2.2.2 Dispensing Area*

The second area in the fueling facility is where the fuel dispensing operation and equipment are located. Dispensing of ***CNG*** is generally approached in the codes as the operation which poses the highest level of inherent risk at a ***CNG*** facility. However, from a design point of view, this increased level of risk is compensated somewhat, as the fueling operation is manned by one or more personnel while the operation is underway. Thus in the event that an incident occurs, it can be quickly identified and mitigated.

There are two basic distinctions in ***CNG*** dispensing areas:

1. Outdoor fueling.

2. Indoor fueling.

While the standards and regulations allow either scenario, there is often considerably more design effort and cost associated with indoor fueling.

Most transit ***CNG*** fueling facilities are geared to the fast filling of buses. This approach most closely resembles a diesel fueling process where a bus moves sequentially and relatively quickly through fueling, service, and cleaning operations. There is another option available with ***CNG***. This second option is referred to as time-fill or slow-fill. In this case, all vehicles are filled simultaneously and directly from the ***compressors***. This system has both advantages and disadvantages over fast-fill systems and the choice of which system to use will be very situation specific. From a facility perspective, it is possible to accommodate either indoor or outdoor

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[8] Several proposals for improving the requirement of ANSI Standards on different equipment used in the compression area are in the "public review and comment" phase. These proposals are listed at the end of this document.

timed-fill, however it is important to remember that the fueling area now includes all of the bus storage area.

NFPA 52 will be referenced throughout this section since at present it is the only standard which addresses this topic.

### 2.2.2.1 Outdoor Fueling

Outdoor fueling is described in NFPA 52 §4-4.2.2 as follows:

*4-4.2.2 A facility in which **CNG** compression, storage, and dispensing equipment is sheltered by an enclosure constructed of non-combustible or limited combustible materials that has at least one side predominantly open and a roof designed for ventilation and dispersal of escaped gas shall be considered to be located outdoors.*

Most outdoor fueling would take place under a canopy with 3 or 4 sides open. Thus, it is necessary only to ensure that the roof cannot trap gas to meet the structural requirements of this area.

**(a) Design Overview-Outdoor Fueling.** The fundamental approach to designing a ***CNG*** dispensing area is to minimize risk to personnel and facility by preventing the gas release, reducing the concentration of gas in the event of a leak, controlling the movement of the leaked gas, reducing the risk of a source of ignition and putting in place safety and warning systems to notify personnel.

Physical separation of the various principal systems in a fueling facility from buildings and property lines could become an issue if a transit agency is already experiencing space and traffic flow problems. NFPA 52 stipulates minimum separation distances between equipment and building **for outdoor facilities** as follows:

*4-4.2.3 Compression, storage, and dispensing equipment outdoors shall be located aboveground, not beneath electric power lines or where exposed by their failure, and a minimum of 10ft (3.0 m) from the nearest important building or line of adjoining property that may be built upon or source of ignition.*

*4-4.2.4 Compression, storage, and dispensing equipment outdoors shall be located not less than 10 ft (3.0m) from the nearest public street or sidewalk line and at least 50 ft (15 m) from the nearest rail of any railroad main track.*

*4-4.2.5 A clear space of at least 3ft(1m) shall be provided for access to all valves and fittings of multiple groups of **containers.***

*4-4.2.6 Readily ignitable material shall not be permitted within 10 ft (3.0 m) of any stationary **container**.*

*4-4.2.7 The minimum separation between **containers** and aboveground tanks containing flammable or combustible liquids shall be 20 ft (6.1 m).*

*4-4.2.8 During outdoor fueling operations, the point of transfer (see definition) shall be located at least 10 ft (3.0 m) from any important building, mobile home, public sidewalk, highway, street, or road and at least 3 ft (1 m) from storage containers.*

*Exception: At the discretion of the authority having jurisdiction, the point of transfer may be located at a lesser distance from buildings or walls constructed of concrete or masonry materials, but at least 10 ft (3.0 m) from any building openings.*

There are no corresponding equipment distance separation standards for an indoor fueling facility. However, NFPA 52, Section 4-4.3 requires the provision of deflagration and explosion venting and specifies other normal ventilation requirements (see below).

**(b) Electrical Equipment—Outdoor Fueling.** NFPA 52 requires that the area surrounding the dispenser (see the schematic diagrams in Figures 2-1a and 2-1b) be electrically classified. There are some ambiguities in NFPA 52, Table 4-12 and Figure A-4-12.(9) Figure 2-1 displays one interpretation of the standards.

The classification of areas by NFPA 52 relates to the definitions in NFPA 70 National Electrical Code (NEC). The NEC specifies the type of equipment and acceptable wiring practices within a given area. NFPA 52 requires that all equipment within 1.5 m (5 feet) horizontally and 1.5 m (5 feet) vertically be suitable for a Class 1, Division 2, Group D area.(10)

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(9) There is disagreement between the magnitude of extent of classified area and electrical division indicated in Table 4-12 and Figure A-4-12. In a recent communication, the NFPA has asserted that requirements of the standard consist of the numbered chapters in NFPA 52 and that Appendix A was not a part of the standard.

(10) Note, however, that several ambiguities related to this table exist as there is a 4.6 m (15 feet) separation from screwed connections required (such as the end of the fill hose) and the pictorial representation of this hazardous location in Appendix B of NFPA 52 1995 designates this area as Division 1, not Division 2. It is recommended that this issue be resolved with local regulatory authorities.

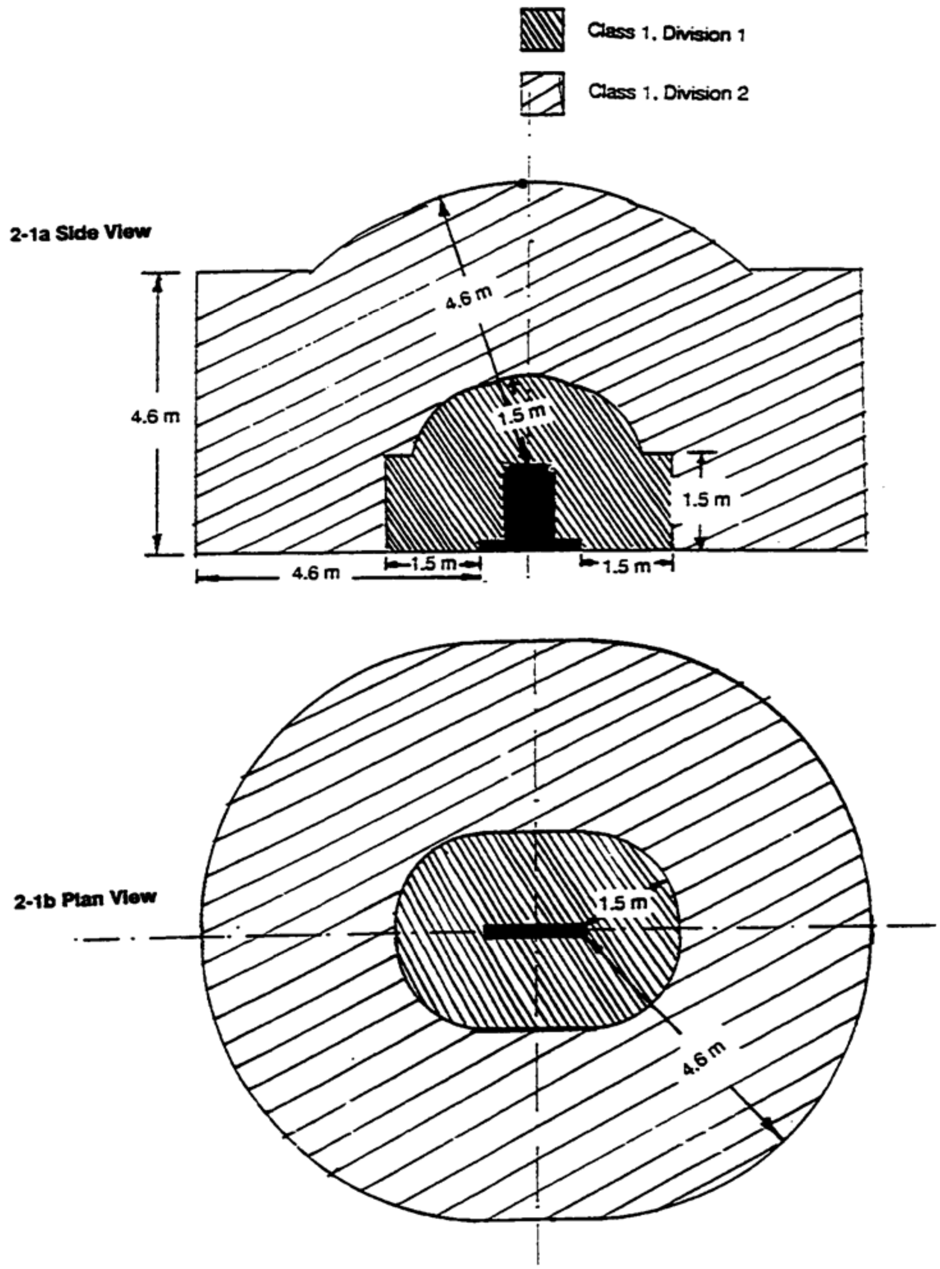
Note: Some transit authorities have elected to exceed standards by utilizing equipment rated for Class 1. Division 1 Group D. This is acceptable from a code standpoint. However, there may be a significant additional cost associated with this approach.

If it is assumed that the hazardous area is intended to be 1.5 m (5 feet) from the dispenser and rated as Class 1, Division 2 Group D, the following need to be considered (for equipment in the hazardous area):

1. All lighting must be lens covered and no surface shall exceed 700 K (800 °F). This lighting will comply with Class 1, Division 2, Group D, but stamped approval of same is not required.

2. All arcing or sparking devices (electrical switches, receptacles, other sources of ignition within the fueling room) must be relocated or be of a hermetically sealed, intrinsically safe or explosion proof type. All electric motors must be Totally Enclosed Fan Cooled (TEFC).

3. All conduit penetrations must be sealed to maintain electrical classification integrity. Wall or barriers which are used to establish classified areas should have all penetrations accommodating piping or conduits sealed to prevent gas migration through the penetrations. NFPA requires that conduits crossing classified area boundaries shall be internally sealed to prevent gas migration through the conduit.




Note: These figures are drawn based on the author's interpretation of the information in Figure A-4-12 in NFPA 52 and the dimensions specified in the NFPA 52, Section 4-12 for different classified regions.

**Figure 2-1**
**Classified Areas In and Around Dispensers**

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 are 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.*

**(c) Heating and Ventilating in the Fueling Area—Outdoor Fueling.** In many outdoor fueling applications, there will not be any heating or ventilating equipment. NFPA 52 does not specify the type of the equipment required within the fueling area although it does indicate that any walls and/or roof must be designed not to accumulate gas.

**To enhance safety, it is prudent** to consider the following in the design of equipment used in outdoor fueling stations that may potentially be in the path of a gas plume if a release occurs:

- Heaters should not pose ignition potential. They should be either electrically classified (Class 1, Division 1) or indirect (forced air) gas fired or steam or hot water, or direct vent combustion type, with the exception of non-recirculating roof top (outdoor) direct fired make-up air units. The temperature of any surface which could contact the gas must not exceed 700 K (800 °F). All fan blades should be made of aluminum or plastic blades so that they are non-sparking.

**(d) Structural Considerations in Fueling Areas—Outdoor Fueling.** NFPA 52 specifies that materials of construction shall be non-combustible or limited combustion. Also this standard specifies the separation requirements between equipment and buildings, property line, etc. (See NFPA 52 citations on page 2-13.)

### 2.2.2.2 Indoor Fueling

Indoor fueling is described in NFPA 52 §4-4.3.1 and storage limits are indicated in §4-4.3.2, as follows:[11]

*4-4.3.1 Compression, dispensing equipment, and storage **containers** connected for use shall be permitted to be located inside of buildings reserved exclusively for these purposes or in rooms within or attached to buildings used for other purposes in accordance with this section.*

*4-4.3.2 Storage shall be limited to not more than 10,000 SCF (283 $m^3$) of **natural gas** in each building or room.*

**(a) Design Overview - indoor Fueling.** The fundamental approach to designing a ***CNG*** dispensing facility is to prevent leaks, minimize risk to personnel and facility by reducing the concentration of gas in the event of a leak, controlling the movement of the leaked gas, reducing the potential for the presence of a source of ignition and putting in place safety and warning systems to notify personnel.

**(b) Electrical Equipment - Indoor Fueling.** The guiding principle in designing the electrical system (for all facilities in which there could be potential ***CNG*** releases) is to eliminate all potential ignition sources within the facility. Where such complete elimination is not possible, the electrical (wiring and equipment) design should reduce the potential for ignition. The design may consider any or all of the strategies involving structural modifications, equipment redesign, positive air/nitrogen flow approach, electrical shutdown ***controls***, etc. That is, both passive

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[11] On-board storage in buses is excluded from the purview of this section of NFPA 52.

designs of ignition source removal or active, real-time shutdown of electrical and high temperature systems should be considered. However, where there are specific local or national code requirements, they should be followed in the design.

For ***CNG*** compression, storage, and dispensing systems, NFPA 52, Section 4-12 stipulates the type of equipment, the degree of electrical classification required, and the extent of classified areas. Because of the importance of these code requirements, the relevant section(s) from NFPA are reproduced below.[(12)]

NFPA®

*4-12 Installation of Electrical Equipment. Electrical equipment shall be installed in accordance with NFPA 70, National Electrical Code,® for Class 1, Group D, Division 1 or 2 locations in accordance with Table 4-12.*

*Exception: Electrical equipment or internal combustion engines installed in accordance with NFPA 37, Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines.*

***Table 4-12 Electrical Installations***

| ***Location*** | ***Division*** | ***Extent of Classified Area[1]*** |
|---|---|---|
| *Outdoors* | | |
| *Discharge from relief valves or vents* | *1* | *5 ft (1.5 m) in all directions from point source* |
| | *2* | *Beyond 5 ft (1.5 m) but within 15 ft (4.6 m) in all directions from point of discharge* |
| *Valves, flanges, or screwed fittings* | *2* | *15-fi (4.6-) radius[2]* |
| *Discharge from relief valve within 15 degrees of the line of discharge* | *1* | *15 ft (4.6m)* |
| *Dispensing equipment* | | |
| *Outdoors[3]* | *2* | *From 0 to 5 ft (0 to 1.5 m)* |

*[1]The classified area shall not extend beyond an unpierced wall, roof, or vapor tight partition.*

*[2]Space around welded pipe and equipment without flanges, valves, or finings is a nonhazardous location.*

*[3]See Figure A-4-12 for an illustration of classified areas in and around dispensers.*

*Exception:* *Listed dispensers shall be permitted to be installed using classified areas in accordance with the terms of the listing.*

*NOTE: The electrical classification specified in Table 4-12 may be permitted to be reduced, or hazardous areas limited or eliminated, by adequate positive pressure ventilation from a source of clean air or inert gas in conjunction with effective*

(12) All dimensions specified in the NFPA 52 code are in British units. These have been converted to SI units to the accuracy of 1 decimal place.

*safeguards against ventilator failure by purging methods recognized in NFPA 496, Standard for Pursed and Pressurized Enclosures for Electrical Equipment. Such changes should be subject to approval by the authority having jurisdiction.*

It is evident from the above table (from NFPA 52, 1995 edition) that classification of the indoor dispenser is not addressed. However, the 1992 edition indicates that indoor dispensing equipment should be classified as Division 1 or Division 2. See the discussion in Section 2.2.2. 1(b) of this document.

**(c) Heating and Ventilating in the Fueling Area—Indoor Fueling.** The purpose of providing ventilation in ***CNG*** fueling facilities, in addition to normal human comfort, is to ensure that no accumulation of flammable concentrations of ***CNG*** vapor occurs within enclosed spaces. Certain minimum ventilation requirements, in terms of volume flow of air, are indicated in NFPA 52 §4-4.3.5. Specifically, the following are required:

> ***4-4.3.5*** *Indoor locations shall be ventilated utilizing air supply inlets and exhaust outlets arranged to provide air movements as uniformly as practical. Inlets shall be uniformly arranged on exterior walls near floor level. Outlets shall be located at the high point of the room in exterior walls or the roof.*
>
> ***(a)*** *Ventilation shall be by a continuous mechanical ventilation system activated by a continuous monitoring* ***natural gas*** *detection system when a gas concentration of not more than one-fifth of the lower flammable limit is present. In either case, the system shall shut down the fueling system in the event of failure of the ventilation system.*
>
> ***(b)*** *The ventilation rate shall be at least 1 cu ft/min per 12 cu ft(1 $m^3$/min per 12 $m^3$) of room volume.*
>
> *NOTE: This corresponds to 5 air changes per hour.*
>
> ***(c)*** *A ventilation system for a room within or attached to another building shall be separate from any ventilation system for the other building.*

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

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

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

NFPA 52 does not specify the type of the equipment required within the fueling area, although it does indicate the minimum level of ventilation.

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

1. Heaters should not pose ignition potential. They should be either electrically classified (Class 1, Division 1) or indirect (forced air) gas fired or steam or hot water, or direct vent combustion type with the exception of non-recirculating roof top (outdoor) direct fired make-up air units. The temperature of any surface which could contact the gas must not exceed 700 K (800 °F). All fans must be aluminum or plastic blades such that they are non-sparking.

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

3. Complying with the ventilation requirements of NFPA 88A §4-3.2 (for enclosed parking garages) of 6 Air Changes per Hour (ACH) for the indoor fueling facility also so as to sweep the ceiling, ensuring that no pocketing can take place.

   (Additional through-the-roof or ducted exhaust fans delivering an additional 6 ACH and activated by the gas detection system have been used at some facilities to quickly dilute and exhaust a fast leak. A high-speed setting on the regular ventilation system could be used to fulfill this requirement.)

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

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

**(d) Structural Considerations in Fueling Areas—Indoor Fueling.** NFPA 52 provides considerable detail on the materials and methods of construction suitable for indoor fueling areas. These requirements as well as additional best practices are outlined below:

1. The roof will be such that the ventilation system or natural ventilation can sweep the ceiling and prevent gas pocketing.

2. NFPA 52 §4-4.3.4 specifies materials and construction methods.

3. NFPA 52 also requires that deflagration panels be provided (see NFPA 52, §4-4.3.3).

4. Full compliance with Item 2 above may not in all circumstances be practical. In such circumstances a 2-hour-fire rated partition or equivalent design (e.g., water curtain) between the fueling area and the main garage designed to close automatically on gas or fire alarm should be considered.

5. NFPA 52 discourages passageways to adjacent rooms from the fueling area as indicated above. However, if such passages are necessary, it is recommended that they be designed with a barrier space with two self-closing vapor-sealed, fire rated doors.

#### 2.2.2.3 Dispensing Equipment Requirements

NFPA 52 provides considerable guidance in the location of safety devices associated with the dispenser itself. Safety features required by the NFPA 52 standards are:

1. The lines from the storage to the dispenser should be equipped with both automatic fast closing valves and manual valves at the storage end and at the dispenser end. It is further required that if the fueling area is indoors that each line entering the building be equipped with a manual isolation valve. (Refer to NFPA 52, §4-11.3, §4-11.5, and §4-11.10.)

2. NFPA 52 requires that dispensers have a breakaway connection on each hose to limit the breakaway force to 660 N (150 lbs.) in the event of vehicle drive away. A manual isolation valve should be provided immediately upstream of this breakaway and a bleed off device should be located between the breakaway and the manual valve. (Refer to NFPA 52, §4-11.7, §4-11.8, and §4-11.11.)

3. NFPA 52 §4-11.4 alludes to excess flow valves but does not require the provision of these valves. If they are required to be used, it should be noted that current technology indicates that they are impractical, particularly with the large flow rates typical of transit ***CNG*** stations. In the absence of these valves, the dispenser should be equipped with electronic shutdown for excess flow and that it should be designed to limit the total fill to any one vehicle to the maximum amount of fuel that the large vehicle would use. In the event of either of these faults, it is desirable to immediately and automatically shut down fueling at all other islands in the area (all fuels) and shut down the ***compressors***. A remote alarm should also be considered.

4. The requirements for the dispensing hose materials and testing are specified in NFPA 52 §4-9.3 and §4-10, respectively. It is, however, prudent to use a hose manufactured of manmade material or one that has stainless steel braids. All hoses must be electrically conductive. Hoses must be designed for ***CNG*** use and must be certified by the manufacturer as such. The hose ends should be installed by the original hose manufacturer, who should pressure test the hose to 1.5 times the rated pressure. Hoses should be equipped with a manufacturer tag indicating the serial number of the hose, the test pressure and the test date. This tag should be marked on site with the first date of service.

Hoses should be discarded after 12 months of use—for hose with carbon steel braid, after six months of use—or immediately after any mechanical abuse such as a breakaway incident.

Hoses should be equipped with retractors or counterweights to ensure that fueling connections do not fall to the ground.

5. The fueling connector should be equipped with a sealed vent back connection which is connected by hose to a pipe to convey this vent back gas to a safe area away from the fueling operation. This hose must decouple so as not to interfere with the breakaway on the main dispenser hose. (Refer to §4-14.7 of NFPA 52.)

6. The dispenser is required by NFPA 52 to include a temperature compensation system. (Refer to §4-14.1, §4-14.2, and §4-14.3.)

   This system is generally electronically controlled and its function is to adjust the fill pressure to account for variations in ambient temperature as well as the heating effect which is common in vehicle cylinders during a fueling cycle. This system must be carefully designed and calibrated to ensure fills as close as possible to complete while not allowing overfills to occur. If this system includes a safety relief valve, it should be piped to a safe location in a separate line from the fueling connection vent back. (See §4-9.2.)

### *2.2.3 Dispensing Area Operations and Procedures*

Existing codes do not address the operational aspects of the fueling area in depth. NFPA 52 specifies some signage requirements as do several of the local codes. It is prudent practice to enforce the following procedures in a fueling facility:

1. Smoking, open flame or spark (including jumper cables) or any other source of ignition **must be strictly prohibited** in the fueling area.

2. Anyone dispensing fuel must be adequately trained in the proper facility procedures and emergency procedures. If local regulations require additional training or certification, this should be regarded as the minimum training requirement.

3. Prior to fueling, the bus engine ignition must be shut off and the parking brake must be set. If a vehicle is parked on any incline or the brakes are not fully locked, the wheels of the bus must be chocked.

4. An employee evacuation plan to be used in cases of 20% LFL alarms (or other emergencies) must be developed and implemented.

5. Performing any type of service or repair to the bus while it is parked in the fueling area (with the exception of normal fluid level and tire pressure inspections and cleaning) should be avoided.

6. Any bus with a known leak must remain outside, or be moved outside if it is safe to do so, until it can be defueled, and the leak isolated. A bus with a known leak should never be fueled.

7. Clearly visible signs indicating NO SMOKING and IGNITION OFF as well as the location of all Emergency Shutdown (ESD) buttons and FIRE pulls must be provided in and around the fueling area.

8. The employees must be trained to activate ESD as the first line of action in the event of a gas leak or any other incident. The area should then be evacuated.

9. Prior to ***defueling*** a bus, ground must be established between the bus, the ***defueling*** stack, and the earth. ***Defueling*** must take place at controlled rates, and a technician must remain with the bus to ensure the proper operation of the ***defueling*** equipment.

### 2.2.4 Safety Control Systems

NFPA 52 requires the use of a combustible gas detection system, on indoor fueling applications, to provide an audible alarm in the event of a concentration of 20% LFL. (Refer to NFPA 52 §4-4.3.6.) NFPA 52, Section 4-15, requires the provision of a portable fire extinguisher having a rating of not less than 20-B:C, at the fueling area. To enhance safety, it is prudent practice to provide, in addition to the above, the following:

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

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

3. A centralized ESD system at the ***CNG*** station which upon activation will terminate dispensing, close all automatic valves on the storage lines, shut down all ***compressors*** and isolate the gas service upstream of the ***gas dryer***. This system must be fail-safe and must require a manual reset. (Refer to §4-11.6 and §4-4.3.7 of NFPA 52.)

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

### 2.2.5 Defueling Equipment

In many instances it may be necessary to ***defuel***[13] a bus. When the fuel system in a ***CNG*** bus is to be maintained, either because of a scheduled maintenance (especially if the maintenance is on the high pressure side) or because of a small leak in the system, the bus should be defueled before being brought into a maintenance garage. ***Defueling*** removes the possibility of a ***CNG*** leak during the maintenance work, especially if the work is on the fuel system.

It is a prudent practice to include a system for ***defueling*** a bus in the transit facility design. In an operating transit facility, if there is no facility for ***defueling,*** the transit agency should consider a retrofit procedure to install such a system.

Controlled ***defueling*** can be performed only if a proper connection is provided on the bus fuel system. It is neither recommended nor is it normally possible to ***defuel*** a bus through the fill port (because of the provision of a back flow check valve on the bus side of the fuel system). In the newer design of ***CNG*** buses, a special adaptor/connector is generally provided at the end of the supply side (fuel) manifold. A standard high pressure quick connect/disconnect fueling nozzle may be used for ***defueling.***

There are several ***defueling*** options. These options include:

1. Downloading fuel by hose from one bus to an empty receiving bus. This method can achieve residual pressures below 7 M Pa (1,000 psig) if 2 to 3 receiving buses are used in sequence.

2. Reintroducing the gas from the bus through one or two stages of regulation to the suction of the ***compressors*** for gas recompression and use in other buses. This method achieves a residual pressure slightly higher than the station inlet pressure. Note that a safety relief valve(s) must be used after each regulator to ensure that downstream line pressure ratings are not exceeded.

3. A similar arrangement to Item 2 above can also be used to introduce gas into the gas service line.[14] This method achieves similar results to re-introduction ahead of the compressor without requiring compressor operation, however, it also has two potential disadvantages: (a) the gas given back to the utility may be without compensation; and (b) the utility may not allow this practice due to the potential damage to the gas lines by operator error.

4. The gas should not be vented to the atmosphere. Venting to the atmosphere is often practiced in combination with one of the other practices to achieve desired results of ***defueling.*** However, this practice has negative environmental effects as well as the cost of the lost gas. The vent down point must be carefully selected to ensure that the

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[13] The word ***"defueling"*** means removing a substantial part of the ***CNG*** inventory from a bus fuel system including from one or more fuel tanks provided the tanks that are full can be isolated by manual shutoff valves.

[14] One transit system has successfully adopted this approach to feed the remainder gas to the facility heating gas system which is at 30 k Pa (5 psig) pressure.

escaping ***natural gas*** plume does not enter a building directly or through an air intake vent.

Additional information on the ***defueling*** procedure is discussed in Section 2.6.8 of this document.

### *2.2.6 Maintenance of Safety Equipment*

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

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 ***CNG*** emergency shutdowns must be enforced.

4. Regular inspection of ***CNG*** 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 shutoffs.

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

As a final check, it is recommended that whenever any person works on classified electrical enclosures or devices, a trained supervisor verifies 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 ***CNG*** fueled buses are discussed in this Section. In certain climates, ***CNG*** transit buses are stored outdoors. Outdoor parking does not present a significant area of safety concern, and therefore is not discussed in this document.

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 (Storage Facility)*

The possibility of ***natural gas*** release from the ***CNG*** vehicles in these facilities is a major cause of concern. ***Natural gas*** leaks can be classified into two types:

1. A ***High Release Rate Event (HRE)*** is characterized by ***natural gas*** 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.

2. A ***Low Release Rate Event (LRE)*** is characterized by ***natural gas*** release from a CNG fueled bus 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 a 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.

In either case, a flammable mixture of ***natural gas*** and air may form in adjacent areas. The dispersion of the gas-air mixture to vapor concentration values below the LFL will be a function of the following:

- ♦ Rate of release and duration of ***natural gas.***
- ♦ Ventilation rate and effectiveness of the ventilation in the areas of release.
- ♦ Geometry of the area where the gas is released (areas of captivation, entrapment or impingement).

In a typical large bus storage area designed to comply with the OSHA ventilation requirements, a ***low release rate event*** presents minimal safety concerns. NFPA 88A currently recommends six air changes per hour. A storage facility designed to alleviate potential dangers from ***low release rate events*** should consider the following issues:

- ♦ Dead air zones and facility geometry.
- ♦ Beam and girder construction and configuration of structural members.
- ♦ Air changes per hour under both normal operation and during emergencies.
- ♦ Size of the facility vis-a-vis the normal ventilation rate. A smaller facility volume reduces the magnitude of the "maximum tolerable leak rate." Ventilation rate should be increased in a smaller facility to maintain the same levels of dilution as in a very large facility.
- ♦ Vehicle design features to reduce releases or notify in event of release.

There are no NFPA or other standards applicable to gaseous storage. In the spirit of safety, it will be prudent to review the applicable Section 5-3.3 of NFPA 30 standards which is applicable to flammable and combustible liquids. However, §5-3.3 of this code relates to ventilation of "processing areas" handling or using Class I or Class II liquids above their flashpoint temperatures.

With ***high release rate leak events,*** vehicle design can control the amount of gas capable of being released due to a severed fuel line or PRD release. It may also be possible with the proper vehicle design and/or operational procedures to minimize the duration of time of high release rate of gas and/or the quantity of gas being released over time.

Given the above, a ***CNG*** bus storage facility design should incorporate the following features:

- ♦ Reducing the volume and/or time of actual release.
- ♦ Keeping potential ignition sources away from the path of the gas plume (which may have vapor concentrations in the flammable range).

- Using proper ventilation (air flow rate values) to control the duration of persistence of ***natural gas*** concentration above the ***lower flammability limit.***

### 2.3.2 Electrical Equipment

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

At present, the requirements for electrical system safety in ***CNG*** bus garages are not available in any national code. However, prudent design of a garaging facility's electrical system should adopt the requirements of NFPA 52 and applicable parts of NFPA 70. A facility's design must take into account special safety features that may be provided on the ***CNG*** buses and other safety equipment which may be installed either on the buses or within the garage premises.(15) These may include such items as automatic ***CNG*** tank isolation valves which limit the amount of gas released, location of tanks on the bus, distance from the bus to nearest electrical equipment, whether the equipment and electrical systems are non-sparking solid state devices, and voltage in the equipment. Where specific electrical classification requirements exist, as a part of the state or local codes, these requirements must be adhered to in the facility design. Also, the basic concepts of safety regulations which may not be directly applicable to a ***CNG*** garage facility must be considered.

NFPA 70 recognizes that not all facilities in which flammable liquids or flammable vapors may escape from their normally confined state need to be classified as Class 1, Division 2 facilities for electrical systems.

### 2.3.3 Ventilation and Heating

In addition to normal building ventilation that is required for a parking facility, ***CNG*** bus storage facilities should be provided with a means to remove any ***natural gas*** leakage. The use of *exhaust* fans should be considered for activation upon detection of a ***natural gas*** concentration of 20% LFL or greater. If exhaust fans are used for this application, these fans should be NEC Class 1, Division 2 classified since they will operate in a gas rich environment. Makeup air supply should be provided by means of low-level ventilation and/or a direct opening to the outdoors.

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

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

The number of exhaust fans and their location should be determined. The design should meet local building code requirements. Care should be taken to have effective air changing, eliminating stagnant air pockets and reducing ***natural gas*** residence times.

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

### 2.3.4 Types of Construction

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

### 2.3.5 Combustible Gas Detection

Consideration should be given to providing a combustible gas detection system in the bus garage. Additional safety benefits will result if a detection system is installed on the bus also.

Combustible gas detection should be provided in areas that will result in the quickest response time to a gas leak. In addition, installing gas sensors at locations where the potential exists for gas accumulation or entrapment will lead to significant improvement in safety. Typically, sensors are mounted at ceiling level to monitor gas. Considerations should be given to detecting gas concentrations in the exhaust duct.

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

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

### *2.3.6 Emergency Systems*

The accidental release of ***natural gas*** should be handled by ventilators, de-energizing of spark producing equipment or classification of electrical components. Therefore, it is important to maintain these systems in working condition even in the event of loss of electrical power or brown out. A back-up power supply is desirable. However, it should be ensured that the back-up 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. Typically, when a fire alarm is activated, ventilation is interrupted and fire rated barriers are closed. Upon natural combustible gas detection, ventilation is increased and barriers are opened to stimulate air movement. One other conflict between fire and natural combustible gas detection systems is the energization of fire alarm bells throughout a facility. Since these bells may be spark producing, they may pose an ignition hazard. The local authority having jurisdiction and the agency's insurance underwriters should be consulted to ascertain the priority level of alarms.

Audible alarms provided as a part of the emergency system should be in compliance with the requirements of the 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 must comply with the requirements of Section 4.28.3 of the Accessibility Guidelines.

### *2.3.7 Safety Interlocks*

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

- Permitting manual resetting of tripped or equipment activated in an emergency.
- Providing audio and visual indications when a detection or other ***natural gas*** equipment is off-line for maintenance.
- Locating key activated interlocks at remote locations (such as next to facility fire alarm panels) for ventilation and reestablishing priority functions in case of a fire/gas emergency.

- ♦ Locating manual trip stations, which provide similar activation of ventilation and electrical ***controls.***

- ♦ Interlocking emergency systems to an "on" default when problems are being encountered or maintenance is being performed on detection or other input notification systems.

### *2.3.8 Operations in a Storage Facility*

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

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

2. Ensuring that no ***CNG*** bus which has sprung a fuel leak, however small the leak rate may be, is ever allowed to be brought into or parked in the garage.

3. Strictly prohibiting smoking except in designated smoking areas.

4. Providing a portable hand-held ***natural gas*** concentration measuring instrument at a convenient and easily accessible location either within or very close to the storage facility. This instrument could be used to detect near ground level gas concentrations if anyone suspects a fuel leak from a bus parked in the garage. Any such detection should be followed by the implementation of an appropriate level of response.

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

6. 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.

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

## 2.4 BUS MAINTENANCE FACILITY

A bus maintenance facility is generally a partial or fully enclosed building within which repairs and routine servicing of buses are performed. In many transit systems, this facility consists of one or more bays consisting of either a lift or a pit over which the bus to be serviced is parked. Also, a majority of transit systems use the same maintenance facility for servicing ***CNG*** and other fuel buses. In large facilities it is common to see several buses being serviced at the same time. Where ***CNG*** buses are serviced in existing diesel bus maintenance facilities, it is common to see a designated part of the facility dedicated to ***CNG*** bus servicing only and this section of the facility being upgraded with the provision of gas sensors, alarms, and special equipment. Discussed below are special issues of design and operational practices of a ***CNG*** bus maintenance facility which should improve safety.

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

In general, all requirements for safety in a bus storage area (discussed in the previous section) should be assumed to be applicable to a bus maintenance facility. However, there are exceptions and somewhat more restrictive requirements in a maintenance facility because of the nature of work being performed in this facility and the (increased) potential for ***CNG*** 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.

### *2.4.1 Design Overview (Bus Maintenance)*

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

It should be noted that in a repair facility vehicles are often left running during maintenance activity. Therefore, the potential exists for larger releases in smaller volumes of space. A maintenance facility is generally smaller than a storage facility. Vehicle design can control the amount of gas capable of being released from a severed fuel line or from a PRD release. It may also be possible with the proper vehicle design and/or operational procedures to minimize the time during which a large quantity of gas could be released and/or the quantity of gas being released over time. In addition, since repair facilities generally require tail pipe back-ups for exhaust, a means to exhaust PRD releases directly outdoors may be practical.

### *2.4.2 Electrical Equipment*

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

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

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

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

### *2.4.3 Ventilation and Heating*

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

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

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

### *2.4.4 Types of Construction*

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

### *2.4.5 Combustible Gas Detection*

All of the requirements for a storage facility discussed in Section 2.3.5 should be construed to be applicable to a maintenance facility. In addition, where maintenance facilities have pits, consideration should be given to installing combustible gas sensors. Also, consideration should be given to providing gas sensors at levels close to the floor at strategic points in the maintenance facility.[(16)]

### *2.4.6 Emergency Systems*

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

### *2.4.7 Safety Interlocks*

The requirements discussed in Section 2.3.7 should be assumed to be applicable to this Section also.

### *2.4.8 Other (Passive) Safety Practices*

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

1. Procedures should be implemented to ensure that no part of the fuel system is impacted, either mechanically (i.e., impacts) or electrically, during the time a ***CNG*** bus is being serviced for non-***CNG*** 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 the ***CNG*** fuel system on a bus is to be serviced.

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

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[(16)] Recent tests conducted with high pressure ***CNG*** releases have indicated that a horizontally released jet of gas close to the floor will linger for considerable duration of time at or close to ground level. This could pose an ignition hazard at floor level. An early detection of this condition and implementation of emergency action will significantly improve safety.

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

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

Refer to Section 2.6 of this document for other personnel training requirements.

### *2.4.9 Maintenance of the Facility Infrastructure*

The issues discussed and requirements identified in Section 2.3.9 are applicable to this Section on maintenance facilities.

## 2.5 BUS FUEL SYSTEM

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

### *2.5.1 Fuel System Design Philosophy*

A ***natural 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. ***CNG*** releases may be of one of the following two types:

- **Small leak event:** characterized by ***natural 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 due to currents generated by its ventilation system.

- **Large leak event:** characterized by ***natural gas*** emanation from a catastrophic failure in the tubing connecting a bank of storage cylinders or a complete discharge by a cylinder ***pressure relief device.*** 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 ***natural 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, and manifolds. The use of redundant critical components to ensure bus operation during severe operating conditions should be considered. As an example, this might entail the selection of a design that incorporates dual high pressure and low pressure regulators in parallel with bypasses for engine fuel supply redundancy.

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

### 2.5.3 Fuel Delivery System Design Checklist

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

- ♦ Design redundancy for fuel supply components that are susceptible to fouling and critical to engine operation.
- ♦ Liberal use of manually operated quarter-turn valves for isolation of equipment and long runs of tubing.
- ♦ Selection of stainless steel tubing for pressure and abrasion considerations.
- ♦ 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.

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

### *2.5.4 Fuel Storage System Design Checklist*

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

- Determination of the number and location of ***fuel tanks***, based on the results of a hazard analysis discussed in Chapter 3 of this document.

- Space availability and economics that determine the most cost-effective approach.

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

- The installation of two different size fueling receptacles should be considered. One of these should be an NGV1 receptacle to facilitate fueling the bus in a location other than at the transit system's fueling facility.

- Provision of manually operated quarter-turn valves for equipment and long run isolation purposes.

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

- Effective placement of pressure gauges.

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

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

- Manifolding of the outlet from all PRDs. Also, the design of the manifold should be such as to provide easy connection to an external exhaust system.

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

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

### 2.5.5 Fuel Delivery and Storage System Operation

The following safe operating practices related to 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 ***natural gas*** in any one system and help prevent a large leak event.

### 2.5.6 Detection and Suppression Systems

There are commercially available systems for onboard fire safety detection and suppression for installation on a bus. These systems can detect the leakage of ***natural gas*** or the heat rise from an onboard 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, onboard locating and alarm systems are commercially available. These systems will annunciate an onboard 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.

### 2.5.7 Precautionary Procedures Prior to Maintenance

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

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

- For major repairs (over four hours of duration), each available quarter-turn shutoff valve on the fuel delivery system should be manually closed. This includes the shutoff valves on the high pressure and low pressure regulators.

♦ 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.


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

### *2.5.8 Defueling Strategy*

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

#### *2.5.8.1 Precautions*

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


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 *CNG* from a bus fuel delivery and storage system and when *natural gas* may be intentionally vented into the atmosphere. It is of paramount importance to properly and adequately electrically ground any tubing or storage system during urgent *CNG defueling* to atmosphere.**

3. **Improper *defueling* of *CNG* to the atmosphere can ignite the *natural gas* fuel in the case of improper electrical ground. This ignition is caused by the static electric charges that build as the *CNG* 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.)

### 2.5.8.2 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 ***CNG*** 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 ***CNG*** remaining in the fuel delivery system is no longer capable of operating the engine. Refer to Section 2.5.8.3, "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 natural gas*** from the bus fuel delivery and storage system to atmospheric pressure, employ the atmospheric venting procedure included in Section 2.5.8.8.

### 2.5.8.3 Run-down Procedure (Preparing for Defueling)

***CNG*** pressures between 5.5 M Pa to 1.4 M Pa (800 psig and 200 psig) can be attained through the run-down procedure, depending on bus storage size and configuration.

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

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

2. Run the bus on ***CNG*** 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 ***CNG*** from the bus and transport it to another location, then the storage vessel must be labeled as containing ***CNG***, tightly fastened to the transport vehicle, electrically grounded at all times and transported according to all applicable DOT requirements.

*Note that CNG tanks on buses are not generally DOT approved vessels. Therefore, a gas filled vessel cannot be transported as a separate unit <u>(if it is not part of the fuel system attached to a bus).</u>*


**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 all venting is completed. If the storage vessel is to be transported containing *CNG* then it should be properly labeled, fastened and grounded to the vehicle while in transportation.**

#### 2.5.8.4 Vent-Back Procedure (Defueling Back into the Gas Main)

***Residual natural gas*** pressures between 5.5 M Pa to 140 K Pa (800 psig to 5 psig) can be attained through the vent-back procedure, depending on the ***natural gas*** supply main's pressure. **Note that the run-down procedure should be performed prior to performing the vent-back procedure.**

The vent-back procedure involves putting the ***CNG*** from the bus storage system into the local ***natural gas*** utility pipelines. If a transit operator is considering this method of ***defueling***, the following issues should be considered at the time of designing the ***CNG*** bus facility.

1. Enter into agreement with the gas supply utility to feed back ***CNG*** from bus tanks into the utility pipeline grid. (Note: in some cases this may not be possible due to technical reasons such as a backflow check valve in the pipeline.)

2. Locate the vent-back connection at a convenient and remote location, away from buildings, open flames, and heavy traffic areas. A pressure regulator may need to be provided in the vent-back line to reduce tank pressure to the pipeline pressure.

3. Obtain the necessary training for transit personnel from the gas utility so that proper and safe procedures can be followed.

4. Negotiate with the utility company, if possible, the economic benefit of feeding unused gas into the pipeline.

Reduction of the ***residual natural gas*** pressure below the gas main's normal operating pressure is not possible through this vent-back procedure.

#### 2.5.8.5 Additional Vehicle Procedure (Defueling to Another CNG Bus)

This strategy requires the use of additional buses to accept the ***CNG*** from the bus to be defueled. This procedure is useful for situations when a vent-back connection is not available on the gas supply main at the transit agency. This procedure is possible only when buses with considerably lower pressures in their ***fuel storage systems*** than the bus to be defueled are available.

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

- Run-down procedure (indicated in Section 2.5.8.3) should be performed prior to initiating this procedure.

- All of the buses used in this procedure must have an onboard ***defueling*** connection in the ***fuel storage system.***

- The lowest pressure attainable with this procedure is the arithmetic average of the initial tank pressures in both buses, assuming that the total fuel capacity in each bus is the same. Therefore, multiple buses may be needed to reduce the fuel pressure in the bus being defueled to a level consistent with atmospheric venting or other procedures.

- The hoses used for ***defueling*** must be rated for at least 35 M Pa (5,000 psig).

- 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.

#### 2.5.8.6 Compressor Inlet Procedure

***Residual natural gas*** pressures between 5.5 M Pa and 140 K Pa (800 psig and 5 psig) can be attained through the compressor inlet procedure, depending on the suction supply pressure to the ***CNG*** fueling station's ***compressor.***

This procedure is useful when there is no vent-back connection on the gas supply main and no buses available with lower pressures for fuel transfer. This procedure can only be performed when the fueling station ***compressor*** is operational and a connection is available on the fueling station's ***compressor*** suction line.

The following design and procedural issues should be noted for performing this type of ***defueling.***

- A connection must be available on the fueling station's ***compressor*** suction line. Also" the check valve, if present on the ***compressor*** suction line, should be upstream of the ***defueling*** connection so that the defueled gas does not over-pressurize the ***natural gas*** supply main.

- The run-down procedure (Section 2.5.8.3) should be performed prior to this procedure.

- The ***compressor*** is operating at the time of ***defueling.***

- The pressure in the ***fuel tanks*** of the bus being defueled is above the normal suction pressure of the ***compressor.***

- Proper equipment, including a 35 M Pa (5,000 psig) rated connecting hose, and other quick connect mating pieces are available.

- All safety procedures should be followed to ensure that there are no gas leaks during the transfer process.

### 2.5.8.7 Urgent Defueling

There may arise emergency situations in which there is a need to remove the ***CNG*** 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**[17] **should *natural gas* be vented directly to the atmosphere.**

### 2.5.8.8 Atmospheric Venting

***"Residual natural gas"*** refers to the ***natural gas*** remaining in the fuel delivery and storage system after the run-down procedure and one of the three ***defueling*** procedures listed above have been effected. ***Residual natural gas*** may be then be released to the atmosphere through this procedure.


**The only time that this procedure can be used as the FIRST AND ONLY STEP to defuel *CNG* from a *CNG*-powered bus is during *urgent defueling!***

The following facility design, regulatory, and procedural issues are to be noted:

- Before designing an atmospheric vent system, the transit organization should consult with the authority having jurisdiction, the local or state department of environmental affairs, and the Federal EPA regarding existing regulations on deliberate venting of ***natural gas*** into the atmosphere. All rules and regulations related to venting should be complied with.

- Atmospheric venting should be performed through a vent stack located in a remote location away from other buildings and ignition sources.

  A minimum 5 cm (2 inch) diameter vertical pipe permanently affixed to a structure or a building can act as a stack. If connected to a building, the exit section of the pipe must be at least 2 m (6 feet) above the top of the building. The pipe should be provided with approved and appropriate connectors and a rated hose for connecting to the ***defueling*** port on the bus.

- The vent stack must be properly grounded electrically.

[17] An "urgent situation" or "emergency condition" is one in which a major release is about to occur, which 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.

- Vent systems should limit the venting of ***natural gas*** at safe pressures, flow rates, and within acceptable noise levels.

- Prior to ***defueling,*** the bus must be electrically connected to the vent stack or properly grounded.

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

## 2.6 PERSONNEL TRAINING

The safe operation of any ***CNG*** bus transit facility will depend very strongly on the level of training given to various personnel throughout the facility as well as on the commitment to safety from management. Safety consciousness can only be achieved by providing continuous training for all personnel (including management). Training programs should be developed to include all personnel who will be directly or indirectly involved in the maintenance, operation, fueling or storage of the ***CNG*** buses. The following individuals (at a minimum) should be provided with formalized 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 2-6 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 ***CNG*** 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 ***CNG***, and any special information on systems installed.

Training in all areas identified in Table 2-6 can be accomplished in a variety of ways. In-house training is probably the most cost-effective way to provide training to 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 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.

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 and 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 ***CNG*** 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.

**Table 2-6**
**Training Topics for Various Personnel**

| Training Topics | Fuelers/ Mechanics | Building Occupants | Bus Operators | Emergency Response Personnel | Local Groups | Manageme nt | 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

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

Some jurisdictions may require special licenses or permits from the fire department to operate ***CNG*** buses. The transit agency should check local regulations to see whether or not these are required. In addition, fire department permits or licenses to operate the fueling station as well as the bulk storage of ***CNG*** and/or the ***CNG*** buses may also be required. 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 facility safety management in a facility handling/storing/or dispensing a hazardous/flammable material such as ***CNG***. 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, etc.) contacts.

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

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

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

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

OSHA

***29 CFR §1910.38 Employee Emergency and Fire Prevention Plan***

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

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

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

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

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

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

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

Because of the potential impacts of a ***CNG*** 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 which 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 CNG facility, local civic groups, school boards, and local businesses should be made aware of any emergency action plans which could affect them in a major gas release incident.

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

# Chapter 3

# Alternative Fuel Facility System Safety Process

## 3.1 SAFETY REQUIREMENTS

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

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

## 3.2 SYSTEM SAFETY PROGRAM

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

The SSPP should:

- ♦ Have as its objective, to provide for the safety of passengers, employees, the public, and equipment.
- ♦ Encompass all system elements and organizations within the transit system.
- ♦ Identify the safety roles and responsibilities of all organizational elements, and require accountability.
- ♦ Designate one individual with the responsibility for the safety of the system who has a clearly defined role 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 MEL-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 comprehension of how the individual system elements interface with each other is essential to the ***hazard*** identification effort.

### *3.3.2 Hazard Identification*

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

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

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

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

There are several ***hazard*** 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 MEL-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.*** 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 ***hazards*** being reduced to an acceptable ***risk*** level. Safety devices may be a part of the system, subsystem, or equipment.

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

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

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

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

**Table 3-1**
**Risk Assessment**

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

| | |
|---|---|
| IA, IIA, IIIA, IB, IIB, IC | Unacceptable |
| IIIB, IIC, ID | Undesirable (allowable with agreement from Authority having jurisdiction) |
| IVA, IVB, IIIC, IID, IIID, IE, IIE | Acceptable with notification to the Authority having jurisdiction |
| 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 ***hazards*** are introduced. In addition, whenever substantive changes are made to the system, analyses should be conducted to identify and resolve any new ***hazards.***

## 3.4 SAFETY PRINCIPLES

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

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

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

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

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

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

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

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

8. Maintenance activities required to preserve specified ***risk*** levels (Table 3-1) involve the elimination of unacceptable or undesirable ***hazard*** conditions during maintenance. These should be prescribed to the individual responsible for ***system safety*** during the design phase. These maintenance activities should be minimized in both the frequency and in the complexity of their implementation. The personnel qualifications required to adequately implement these activities should also be identified.

## 3.5 VERIFICATION AND VALIDATION

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

The verification and validation process should include:

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

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

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

# Glossary

**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.)

**Buffering** The process by which the transients of CNG line pressure created when a compressor is operating are damped by providing one or more high pressure CNG storage tanks between the compressor outlet and the CNG filling station. Buffer storage tanks, in general, do not have sufficient volume to store significant quantities of CNG.

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

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

**Compressors** The compressors are generally supplied as packaged pre-engineered equipment. The compressors increase the pressure of the gas from pipeline conditions (generally 10 psig to 300 psig) to the maximum required fill pressure (generally 3600 psig for 3000 psig buses and 4500 psig for 3600 psig buses).

**Container** A pressure vessel, generally of cylindrical shape, used to store the compressed natural gas.

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

**Defueling** is defined as removing all of the CNG inventory from a bus fuel delivery and storage system by allowing contained CNG to flow to a lower pressure and then to atmospheric pressure.

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

**Diesel Fuel** Diesel fuel is 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 meters of natural gas 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 vapor concentrations in a fuel-air mixture over which burning can occur. Below the lower flammability limit there is not enough fuel to burn. Above the higher flammability limit there is not enough air to support combustion.

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

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

**Fuel Tank** A CNG container on board the vehicle.

**Gas Dispensers** The gas dispensers often look and function much like a diesel dispenser. CNG is a sealed system that requires no venting during a normal fill cycle. The dispenser is "smart" enough to control its own fill pressure and the required cycling of valves. For these reasons no special certification of fueling personnel is generally required.

**Gas Dryer** Virtually all CNG facilities in the U.S. will require the use of a gas dryer to reduce the moisture content of the gas to levels which are acceptable under the Society of Automotive Engineers (SAE) J1616 recommendations. This equipment is normally located upstream of the compressor.

**Gas Storage** Storage vessels are used to store a volume of gas to reduce the potential of compressor short cycling. On smaller stations this volume of gas may be used to enhance the fill speed through cascading. On larger stations (which includes most transit stations), however, the storage functions as a buffer and buses are generally filled directly from the compressor.

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

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

**High Release Rate Event (HRE)** This is characterized by natural gas 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.

**Lower Flammability 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 release from a CNG 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.

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

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

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

**Nurse Tank** A mobile tank used to supply natural (or any other) gas to a stranded vehicle.

**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.

**Residual Natural Gas** This refers to the natural gas remaining in the fuel delivery and storage system which is at or near gas main supply pressure.

**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, and heptane, are examples of a saturated hydrocarbon.

**Scheduled Defueling** The planned removal of CNG 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 6.45 implies that one kg of fuel requires 6.45 kg of air for 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 Flammability Limit** The maximum volume concentration of a combustible vapor in a mixture of vapor and air at normal temperature which can sustain the propagation of a flame in the mixture and which cannot sustain a stable and steady flame front throughout the mixture at higher concentrations.

**Urgent Defueling** The immediate, unplanned removal of CNG 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/L for the fuel to the LHV of gasoline or diesel fuel in MJ/L.

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

## List of Acronyms

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

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

# Glossary of Graphic Symbols

Information

Caution

Occupational Safety & Health Administration Logo

National Electrical Code Logo

U.S. Department of Transportation Logo

National Fire Protection Association Logo

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## Proposals for Improving the Requirement of ANSI Standards on Equipment Used in the Compression Area

## Currently Under "Public Review and Comment" Phase

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