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Federal Transit Agency

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CLEAN AIR PROGRAM
SUMMARY OF ASSESSMENT OF THE SAFETY, HEALTH, ENVIRONMENTAL AND SYSTEM RISKS OF ALTERNATIVE FUELS

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

Federal Transit Administration

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Michael J. Murphy, H. Norman Ketola, Phani K. Raj

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13. ABSTRACT (Maximum 200 words)
This is a handbook of safety, health, and the environmental issues of the production, bulk transport, and bulk storage of alternative fuels with emphasis on transport and storage. Fuels included are: 1) compressed natural gas, 2) liquefied natural gas, 3) propane, 4) methanol and methanol blends, 5) ethanol and ethanol blends, 6) biodiesel, 7) hydrogen, and 8) electricity. Material in the handbook is organized by fuel and by the following topics: 1) general properties of the fuel that effects fire hazards, 2) potential fire hazards during bulk transport, 3) potential fire hazards during unloading to bulk storage, 4) potential fire hazards during fleet storage, 5) other safety hazards, particularly, high pressure and low (cryogenic) temperatures, 6) toxicity of the fuel, and 7) environmental effects of spills onto land or water. Specific properties of the alternative fuels examined include: 1) flash point temperature, 2) range of flammability limits, 3) autoignition temperature, 4) flame temperature, luminosity, and thermal radiation, 5) electrical conductivity, 6) storage temperature and pressure, 7) toxicity of the fuel based on inhalation, skin contact, and ingestion, 8) compatibility (i.e. corrosivity) with other materials, and 9) time or ageing effects. The consequence or potential damage from fire or explosion are given. The hazards of the fuels discussed in the handbook are, in some cases, compared to the reference fuels of gasoline or diesel fuel. In many instances, the state of knowledge of specific hazards and/or ongoing research are noted.

14. SUBJECT TERMS

Alternative Fuels, compressed natural gas, liquefied natural gas, propane, methanol and methanol blends, ethanol and ethanol blends, biodiesel, hydrogen, and electricity, safety, health, environmental, system risks

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PREFACE

National goals for both energy security and clean air have resulted in heightened interest in the use of alternative motor fuels (AMFs) in the transportation market. The growth of interest in alternative fuels has expanded not only the numbers of alternative fuel vehicles, but also the list of viable alternative transportation fuels.

Thus, an increasing number of transit fleets and other fleet owners are operating vehicles on alternative fuels - often with a minimum of technical guidance related to the possible safety or operational impacts on traditional fleet operations, including fueling, inspecting, and cleaning vehicles, as well as performing the light and heavy maintenance activities necessary to keep the fleet in operation.

Moreover, the buildings or facilities used for storing, loading, and maintaining alternative fuel vehicles form an important portion of a fleet operation. Here, the experience with fire and building codes is not yet complete. This situation requires additional care on the part of the owners of these facilities to recognize all hazards associated with the use of alternative fuel vehicles and to ensure that these hazards are properly addressed in the design and operation of the facility.

Experience has shown that not all local community and regulatory groups view the use of alternative fuels as a purely positive option. Transit properties and others who propose the use of alternative fuels need to deal not only with the perceptions of fire and building code officials who grant approvals, but also with the perceptions and concerns of community and neighborhood organizations. The concerns of these groups are not limited to fleet operations, but may also include the production of the alternative fuel and the transportation of the fuel to the point of use.

In view of the diversity of these safety concerns, as well as the number of possible hazards, a comprehensive and systematic program is needed to recognize and organize the existing knowledge about the health, safety, and environmental hazards of alternative fuels and to identify where additional study is needed. The objective of this report is assist the Volpe Center, FTA and DOE in providing information on these issues to the transit and fleet operator community while avoiding a commitment to or bias against any given fuel or point of view.

This report presents the results of a research effort undertaken for the Volpe National Transportation Systems Center. This work was funded jointly by the U.S. Department of Transportation, Federal Transit Administration Office of Engineering and the U.S. Department of Energy, Alternative Fuels Utilization and Analysis Division. The interest, insight and advice of David Knapton of the Volpe National Transportation Systems Center, John Russell of the U.S. Department of Energy, and Tony Yen and Steven Sill of the Federal Transit Administration are gratefully acknowledged.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

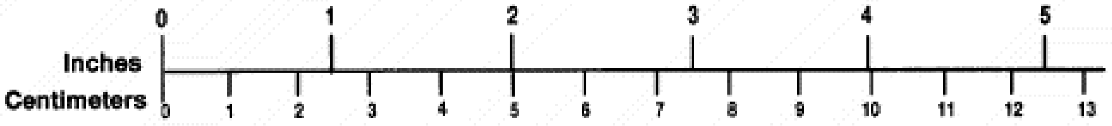
1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

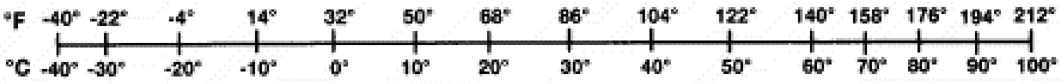
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



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EXECUTIVE SUMMARY

A. BACKGROUND

National goals for energy security and clean air have resulted in a heightened interest in the use of alternative transportation fuels. This growing interest in alternative fuels has led to both an increase in the number of alternative fuel vehicles, and to an expansion in the list of candidate alternative fuels.

This summary assessment consists of two parts. The first part considers the hazards associated with the bulk transport and storage of alternative fuels. The second part considers the hazards associated with the operation, fueling, and maintenance of alternative-fuel vehicle fleets. The report does not cover estimating the hazard probability or calculating the overall risk.

Both sections of the hazard assessment discussion include information on the following alternative fuels:

1. Compressed Natural Gas (CNG)
2. Liquefied (LNG)
3. Propane
4. Methanol and methanol blends
5. Ethanol and ethanol blends
6. Biodiesel blends1
7. Hydrogen
8. Electricity

B. PRODUCTION, TRANSPORT AND BULK STORAGE HAZARDS

The types of hazards which may be encountered, are categorized as follows:

- Safety Issues, including fire hazards and other hazards
- Health Issues, including fuel toxicity
- Environmental Issues, including effects of fuel spills.

Highlights of this analysis follow.

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[1] In this analysis biodiesel fuel is considered to be a mixture of 10-30 percent of a vegetable oil ester, such as methyl soyate, and conventional diesel fuel.

Fire Hazards

Since all fuels bum, they constitute fire hazards to a greater or lesser degree. However, fuels vary widely in the degree of flammability. Of the many combustion-related properties of substance, fuel flammability limits and pool bum rate are especially relevant to a safety hazard analysis.

Fuel Flammability Limits

Flammability limits are a basic measure of flammability. Flammability limits are the range of composition over which mixtures of fuel and air will bum. At an ambient temperature of 22 C, natural gas in the form of CNG or LNG has the widest flammability limits. Due to increased volatility at higher temperatures, the alcohols, methanol and ethanol have extended flammability limits at elevated temperatures (60 C). Biodiesel fuel is below its flashpoint at 22 C and shows a flammable range only at elevated temperatures.

Fuel Pool Burn Rate

If liquid fuels spill and ignite, the pool burn rate is a measure of the rate at which a given size spill will burn and release heat. Since fuels bum only when they are in gaseous form, the pool bum rate tends to be limited by the rate of vaporization. Thus, the pool burn rates for the alcohols, which have relatively high heats of vaporization, are lower than those for hydrocarbon fuels like gasoline or propane. Note too, that the gaseous fuels hydrogen and compressed natural gas can have very high heat release rates since the bum rate for these fuels is not limited by the need to first vaporize a liquid.

Health Hazards

In addition to fire hazards, the use of alternative fuels can present health hazards. For most fuel health effects, inhalation of fuel vapors is the most likely exposure route. The threshold limit value for the health effects of fuel vapors is a measure of fuel toxicity. The limits for all fuels except LNG vapor (considered to be nearly pure methane), and hydrogen are based on toxic effects. The limit values for these fuels are based on the lower flammability limit and the premise that inhalation of a flammable mixture of fuel and air constitutes a health hazard. In the case of hydrogen and natural gas, excessive exposure can also result in asphyxiation. However, approximately 140,000 ppm (14 percent) of an inert gas would be required to lower the oxygen concentration of air to less than the 18 percent, the limit for a breathable atmosphere.

Methanol and methanol blends are the most toxic AMFs for inhalation-exposure with a threshold limit value - time weight average (TLV-TWA) concentration value of 200 ppm. By comparison, the next lowest TLV-TWA concentration value for an AMF includes ethanol 1,000 ppm, followed by natural gas at a value of 10,500 ppm. In addition, there is an OSHA-set personnel exposure time limit (PEL) of 1,000 ppm for propane.

Environmental Hazards

The spill or leak of an AMF is not likely to result in any long term environmental damage. A review of the potential environmental hazards for each AMF, that is not gaseous at normal temperatures and pressures, shows that all of the liquid AMFs are biodegradable over a reasonably short period of time (i.e., a period of several months or less). The major concern is that the liquid AMF should be prevented from entering into any waterway or drainage system. Aside from any consideration of aquatic toxicity, there is actually a potential fire/explosion safety hazard situation created when a flammable or combustible liquid enters a waterway where there are covered sections where vapors can accumulate. This problem is particularly acute for the alcohols (methanol and ethanol) since they are soluble in water. Once such alcohol AMFs have mixed with water there is no simple and low cost method for separating them out.

C. FLEET USE HAZARDS

This portion of the work was structured around a summary list of safety, fire, and health hazards for each alternative fuel in fleet use. In each instance, the assessment of the consequences of the hazards and of the state of knowledge concerning the hazards is based on a comparison with diesel or gasoline fuel as currently used by fleet operators and transit agencies.

To construct the summary list of hazards associated with the fleet use of alternative fuels, the following eight hazardous properties are included:

(a) Flammability
(b) Corrosivity
(c) Toxicity (including asphyxiation)
(d) High pressure
(e) High temperature
(f) Cryogenic temperature
(g) Mechanical energy (includes energy stored as potential or kinetic energy)
(h) Electrical energy

The existence of these hazardous properties and their associated hazards is not sufficient to cause an accident. Some event is necessary before the hazard and the hazard consequences are realized.

The application of the eight hazardous properties to the eight alternative fuels produces a number of hazards. The more significant hazards for each fuel are:

CNG - Important hazardous properties and hazards for CNG include:

- Flammability hazard -- fire or explosion from ignition of gas leaks. Such gas leaks can occur from fuel dispenser or fuel system damage, use of improper components, or poor overall design. High pressure natural gas leaks can ignite from static electricity. Several such cases have already occurred, some resulting in the loss of the vehicle.
- Toxicity hazard - natural gas can accumulate in enclosed spaces. The odorant may not provide sufficient warning of the actual gas concentration.
- High pressure hazard - fuel tank explosion, missile damage from failure or improper assembly or disassembly of fuel system components. Flailing of fuel hoses and fuel lines.
- Mechanical energy hazard - natural gas compressors have rotating and/or reciprocating parts moving it high speeds. Failure of such equipment could lead to missile damage from fragments.

LNG - Important hazardous properties and hazards for LNG include:

- Flammability hazard - fire or explosion from ignition of leaks of fuel. Non-odorized fuel gas increases the hazard. Note that the design base for cryogenic fuel system components is still relatively small.
- Toxicity hazard - asphyxiation from exposure to non-odorized fuel gas. High pressure hazard - while LNG storage pressures are not as high as those for CNG, they are still significant. Also, trapped liquid fuel can produce extremely high pressures upon warming and vaporization.
- Cryogenic hazards - LNG presents several hazards associated with the cryogenic property of the fuel:

  Personal injury may occur from exposure to cold fuel or fuel vapors. This is especially true if proper personal protective gear is not worn.

  Structural failure can occur due to stress from contraction of structural members exposed to cold fuel or fuel vapors.

  Structural failure can also occur due to embrittlement of materials exposed to cold fuel or fuel vapors.

Propane - Important hazardous properties and hazards for propane include:

- Flammability hazard - propane gas can collect in low spaces; large propane vapor clouds can detonate.
- Toxicity hazard - propane gas can collect in low spaces and therefore displace the air necessary for breathing.

Methanol and Methanol Blends - Important hazardous properties and hazards for methanol and methanol blends include:

- Flammability hazard - vapors in fuel tanks are within the flammable range for typical ambient temperatures.
- Flammability hazard - the flames from methanol fires are not as luminous as those from other hydrocarbons. While this serves to limit fire injury and damage, it can also make initial detection of methanol fires more difficult.
- Corrosivity hazard - being a polar liquid, methanol is slightly acidic and can corrode some active metals.

Ethanol and Ethanol Blends - Important hazardous properties and hazards for ethanol and ethanol blends include:

- Flammability hazard - vapors in fuel tanks are within the flammable range for typical ambient temperatures.
- Corrosivity hazard - being a polar liquid, ethanol is slightly acidic and can corrode some active metals.
- Toxicity hazard - ingestion of a fuel billed as food-based, but which must be denatured, i.e., made poisonous.

Biodiesel - Important hazardous properties and hazards for the biodiesel component of biodiesel fuel blends include:

- Corrosivity hazard - elastomer or polymer component failure due to the composition difference between biodiesel fuel and gasoline or conventional diesel fuel is a type of corrosivity hazard.
- Toxicity hazard - ingestion of a fuel which has been billed as non-toxic, but which is generally an ester of a fatty acid and methanol. If ingested the methanol component is released. In primates (including humans) this can cause toxic effects.

Hydrogen - Important hazardous properties and hazards for hydrogen include:

- Flammability hazard - fire or explosion from ignition (especially static ignition) of gas releases or gas leaks. Note that hydrogen fuel is a non-odorized flammable gas.
- Corrosivity hazard - hydrogen embrittlement of certain materials represents a type of corrosivity hazard associated with hydrogen.
- High pressure hazard - fuel tank explosion, missile damage from failure or improper assembly or disassembly of hydrogen fuel system parts.

Electricity - important hazardous properties and hazards for electricity include:

- Flammability hazard - fire caused by electrical malfunctions, such as short circuits.
- Corrosivity, toxicity, or high temperature hazard – from contact with battery electrolyte.
- Electrical energy hazard - electric shock.

D. CONCLUDING REMARKS

No fuel is free from hazards. Although some fuel hazards are obvious, a systematic consideration of hazardous properties and hazards can identify hazards which may have been overlooked. Hazards differ for various alternative fuels. This implies that:

- Modifications of equipment and procedures will be required for each alternative fuel.
- No alternative fuel will be a "drop in" replacement for the status quo.

The full report from this study provides a framework for organizing information about additional hazardous properties and hazards. However, a risk assessment, including information about hazard probabilities and hazard consequences, can support conclusions about the safety ranking of various fuels, fuel systems, fueling equipment, and overall strategies for using alternative fuels.

LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AMF	Alternative motor fuel
API	American Petroleum Institute
BLEVE	Boiling Liquid Expanding Vapor Explosion
C	Celsius
CAP	Clean Air Program
CARB	California Air Resources Board
CNG	Compressed Natural Gas
CO	Carbon monoxide
DOE	Department of Energy
EMI	Electromagnetic interface
EPA	Environmental Protection Agency
F	Fahrenheit
FTA	Federal Transit Administration
kPa	Kilo Pascals (1 psia = 6.9 kPa)
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MPa	Mega Pascals
M-100	Neat (100 percent) methanol
M-85	Mixture of 85 percent methanol and 15 percent gasoline
NFPA	National Fire Protection Agency
NIOSH	National Institutes of Occupational Safety and Health
NOx	Nitrogen oxides
OEM	Original equipment manufacturer
OSHA	Occupational Safety and Health Administration
PEL	Personal exposure limit
PRD	Pressure relief device
psi	Pounds per square inch
psig	Pounds per square inch gage
RFG	Reformulated gasoline
RLM	Refrigerated liquid methane
RMP	Risk Management Plan
RPT	Rapid-phase transition
RVP	Reid vapor pressure
SCRTD	Southern California Rapid Transit District
STEL	Short term exposure limit
TLV	Threshold limit valve
TWA	Time-weighted average
VNTSC	Volpe National Transportation Systems Center

1. INTRODUCTION

1.1 BACKGROUND

The national goals for both energy security and clean air have resulted in heightened interest in the use of alternative motor fuels (AMFs) in the transportation market. The Energy Policy Act of 1992 (EPACT) contains specific requirements for fleet use of alternative fuels. In a number of regions of the country, primarily where air quality is an issue, state and local clean air initiatives and fuel mandates have been enacted for certain vehicle classes. These mandates will have consequences for a number of transit and other fleets that must comply with local, state, and federal regulations while continuing to provide the highest quality transit programs and other services in their areas.

Other government programs have sought to encourage the use of alternative fuels through grants and awards for alternative fuel demonstration programs. For example, as part of its Clean Air Program (CAP), the Federal Transit Administration (FTA) has awarded grants for alternative fuel demonstration programs. The Department of Energy, through the National Renewable Energy Laboratory has also funded a number of alternative fuel demonstration programs, such as the comprehensive CleanFleet program involving Federal Express medium-duty delivery trucks.

Growth of interest in alternative fuels has expanded not only the number of alternative fuel vehicles, but also the list of viable alternative transportation fuels. In recognition of the increasing need to more fully understand critical aspects of the candidate AMFs, the FTA and the Volpe National Transportation Systems Center (VNTSC) have established a program that addresses the safety hazards and operational issues associated with the use of alternative fuels by vehicle fleet operators.

This effort to supply additional information concerning the safety hazard implications of all AMFs is timely. An increasing number of transit fleets and other fleet owners are operating vehicles on alternative fuels - often with a minimum of technical guidance related to the possible safety or operational impacts on their facilities, as well as those related to the production, transport, and bulk storage of alternative fuels that support these demonstrations.

The environmental, safety hazard, and health aspects analysis of AMFs have become more complex in recent years. Several developments have contributed to this complexity. The first development is the increasing number of candidate alternative fuels. For example, at first, methanol was the only alternative fuel being seriously considered for transit use. The early commitment by Detroit Diesel Corporation to provide a methanol fueled-engine for transit use contributed to this emphasis. However, natural gas engine development soon followed, with the natural gas being stored in compressed form.

The roster of alternative fuels used in transit has now expanded to include methanol and methanol blends (M-100 and M-85), ethanol and ethanol blends (E-95 and E-85), compressed natural gas (CNG), propane (LPG), liquefied natural gas (LNG), bio-diesel, and electric batteries, with additional interest in reformulated gasoline and advanced diesel, fuel cells, and even hydrogen as fuels for transit and other fleets.

The second development is the realization that some previous safety analyses have concentrated on only a portion of the total transit or fleet operation. Transit properties and fleet operators must consider the entire path from the fuel supplier all the way to the vehicle fuel tank. Also, fleet operations involve not only operating alternative fuel vehicles in revenue service, but also fueling, inspecting, cleaning, washing, and performing the light and heavy maintenance activities necessary to keep the fleet in operation.

The buildings or facilities used for storing, loading, maintaining, and sometimes fueling, alternative fuel vehicles form an important portion of a fleet operation. Here, the development of fire and building codes is not yet complete. This requires additional care on the part of the designers and owners of these facilities to consider all hazards associated with the use of alternative fuel vehicles and to ensure that these hazards are properly addressed in the plans for and the operation of the facility.

The third development, which adds to the complexity of alternative fuel use, is the recognition that more hazards must be considered than the traditional "Will it bum or explode?" examination of fuel issues. The use of compressed gases raises issues concerning high fuel system pressures. LNG has the potential to cause blindness if splashed in the face. Methanol and denatured ethanol are toxic to humans. Ethanol fuel raises the issue of diversion for non-authorized use. Several fuels demand a further scrutiny of the need for personal protective gear.

Lastly, the experience of some transit properties and private fleet operators has shown that not all local community and regulatory groups view the use of alternative fuels as a purely positive option. Opposition from neighborhood groups has already caused alternative fuel plans in several cities to be changed or curtailed. Transit properties and others who propose the use of alternative fuels need to deal not only with the perceptions of fire and building code officials who grant approvals, but also with the perceptions and concerns of community and neighborhood organizations. The concerns of these groups are not limited to fleet operations, but may also include the production of the alternative fuel and the transportation of the fuel to the point of use. It is important that the fleet operator recognize at the beginning of a conversion to alternative fuels the types of safety issues that will need to be addressed to satisfy these constituencies.

In view of the diversity of these safety concerns, as well as the number of possible hazards, a comprehensive and systematic program is needed to recognize and organize the existing knowledge about the health, safety, and environmental hazards of alternative fuels and to identify where additional study is needed.

The existence of special safety concerns does not mean that alternative fuels are inherently more dangerous than conventional fuels, but does emphasize that forethought, good engineering, and thorough training are requisites for the safe and successful use of alternative fuels. Programs in which alternative fuels are used while all other aspects of the fleet operations remain unchanged are apt to have difficulties.

1.2 OBJECTIVES AND SCOPE

This study is intended to provide a systematic assessment of the safety hazards of AMFs from a fleet operations perspective. It is narrowly focused on the hazards associated with moving the fuel from the point of production to the point of use (bulk transport), the process of transferring the fuel from the transport vehicle, and on- site storage at the fleet operator's facility. The types of hazards that may be encountered during bulk transport, transfer, and storage generation have been categorized as follows:

- Safety Issues
  - Fire Hazards
  - Other Hazards

- Health Issues
  - Fuel Toxicity - inhalation/skin exposure

- Environmental Issues
  - Effects of spills

Six candidate fleet motor fuels received primary consideration during the assessment process. These fuels and the automotive engines that are specifically designed to use the fuel have been the subject of extensive research and development. The fuels are:

- Compressed Natural Gas (CNG)
- Liquefied Natural Gas (LNG)
- Propane
- Methanol and Methanol Blends (M-85, etc.)
- Ethanol and Ethanol Blends (E-85, etc.)
- Biodiesel
- Hydrogen
- Electricity

Hydrogen-fueled vehicles, including those using a fuel cell-electric drive, are just being introduced into actual operations on a prototype/demonstration basis. Battery-powered vehicles have received increased attention in recent years, including a number of applications involving battery electric transit buses.

The overall objective of this report is to organize, analyze, and present existing information about the potential hazards of the AMFs selected for this study. The specific focus is on the hazards associated with potential leaks and spills of the AMFs in the bulk transport, unloading, fleet storage processes, and fleet operations.

It should be noted that all of the potential hazards considered in this report are "acute" hazards, i.e., immediate- or short-term hazards. Long-term ("chronic") hazards have not been addressed.

2. PREPARATION AND ORGANIZATION OF REPORT

2.1 INFORMATION SOURCES

The major sources of information used to conduct the assessment of safety, health, and environmental hazards associated with each AMF come from the following:

- Recent key reports that cover one or more of the hazard assessment issues.
- Information gathered through contacts and interviews with industry officials, trade groups, and government agencies.

The key references used to acquire information are provided at the end of this report in References - Section Three.

The following agencies and organizations were contacted for information on AMFs:

- U.S. Department of Energy
- U.S. Environmental Protection Agency
- U.S. Department of Transportation
- Gas Research Institute
- National Hydrogen Association
- National Soydiesel Development Board
- Massachusetts Division of Energy Resources
- New York State Energy Research and Development Authority
- Boston Gas Company
- Boston Edison - Travelectric Services Corp.
- Commonwealth Gas Company

2.2 ORGANIZATION OF REPORT

This report is composed of two main sections reflecting the two project tasks. The first section, "Production, Bulk Transport, and Bulk Storage of Alternative Fuels," focuses on the hazards associated with moving the fuel from the point of production to the point of use at the fleet operators facility. The second section, "Use of Alternative Fuels by Vehicle Fleets," focuses on the operation, fueling, and maintenance of alternative fuel vehicles. Both sections include discussion of the following fuels:

- Compressed Natural Gas (CNG)
- Liquified Natural Gas (LNG)
- Propane
- Methanol and methanol blends
- Ethanol and ethanol blends
- Biodiesel
- Hydrogen
- Electricity

Within the first section, the report is organized around a discussion of the properties, safety issues, health issues, and environmental issues applicable to each alternative fuel, with sections on methodology, an analysis of issues, and a summary assessment of risks. The safety issues considered include:

- General properties affecting fire hazards
- Fire hazards during transport
- Fire hazards during unloading to fleet storage
- Fire hazards during fleet storage
- Other hazards (e.g., high pressure, low temperature)

Within the second section, the report is organized around a summary list of hazards of each alternative fuel. An introductory discussion considers the types of hazards considered and the distinctions between hazardous fuel properties, hazards, and risks. The summary list of hazards follows. It is accompanied by a selection of actual case histories which serve to illustrate various hazards in the summary list of hazards.

For the summary list of hazards of alternative fuels, the following hazardous properties are considered:

1. Flammability
2. Corrosivity
3. Toxicity (including asphyxiation)
4. High pressure
5. High temperature
6. Cryogenic temperature
7. Mechanical energy
8. Electrical energy

Although this document intends to be a comprehensive list of safety hazards, it is not a risk assessment in which the risk associated with the use of various alternative fuels are ranked or compared. The definitions on the following page will help clarify these terms as used in this report.

Two separate sections of source material are included. Appendix A, titled "Sources for Alternative Fuel Safety Information" provides a bibliography, by categories, which gives basic information for readers. Specific references in the text of the report are given in "References - Section 3" and "References - Section 4."

DEFINITIONS

An *accident* is a general term for an unplanned event with undesirable consequences

A *hazardous property* (or *hazardous condition*) is a physical or chemical property of a substance of situation that has the potential to cause harm. For example, a substance may be flammable or it may be contained under a high pressure.

A *hazard* is the combination of a *hazardous property* with an outcome that can cause damage or harm to people, property, or the environment. For example, a material which is flammable may ignite and result in a fire. Or a material at high pressure may release that pressure quickly, resulting in an explosion. Thus, it is common to speak of "fire hazards" or "explosion hazards" or to discuss the hazard of fire or the hazard of explosion.

A *hazard event* (or *initiating event*, or just *event*) is an occurence involving equipment failure, human action or external cause that results in a hazard. For example, the ignition of a flammable material can cause a fire, while the rupture of a pressure vessel can result in an explosion

The *hazard probability* is the chance that the hazard will occur. The hazard may be thought of as a combination of a hazardous property with the probability of one or more initiating events. For example, the probability of a fire may depend on the probability that a fuel spill could occur coupled with the probability that an ignition source is available. Hazard probability may be expressed in purely numerical terms, such as the number of expected events per year or by using other qualitative or quantitative scales.

The *severity* of a hazard is a measure of the possible consequences of that hazard in terms of property damage or the amount of injury. For example, the severity of a fire hazard may be ranked by the dollar value of the property which may be destroyed. Other qualitative or quantitative scales of severity may also be used. A given hazard may have many possible consequences, so the severity of a hazard often depends on the hazard scenario. For example, for a given type of fuel, the fire hazard severity may be greater if the amount of fuel is greater, or if the equipment configuration allows it to burn more rapidly. Or, the severity of an electrical shock hazard is usually greater if the voltage is greater.

Risk is the combination of a hazard, a hazard probability, and a severity. For example, the risk of a vehicle fire is a combination of (a) the hazard - the vehicle burning, the hazard probability - (b) the chance of this event occurring, and (c) the severity of the damage - the amount of damage to the vehicle and/or the extent of injury to the occupants.

3. PRODUCTION, BULK TRANSPORT, AND BULK STORAGE OF ALTERNATIVE FUELS

3.1 INTRODUCTION

This section provides a detailed description of each AMF of interest, along with a discussion of its special characteristics that affect safety, health, and the environment. Each AMF is presented separately using the following format:

- General Description
  (A brief summary of production sources and the general characteristics of the fuel.)

- Safety Issues
  (a) General Properties Affecting Fire Hazards
  (b) Fire Hazards During Transport
  (c) Fire Hazards During Unloading to Fleet Storage
  (d) Fire Hazards During Fleet Storage
  (e) Other Hazards (e.g., high pressure, low temperature)

- Health Issues

- Environmental Issues

The order of presentation of the AMFs is as follows:

- Methanol/Methanol Blends
- Ethanol/Ethanol Blends
- Compressed Natural Gas
- Liquefied Natural Gas
- Propane
- Biodiesel
- Hydrogen
- Electricity

3.2 METHODOLOGY

It was apparent after a number of the key reports and reference documents had been collected that the amount of information available is very extensive. In order to provide a comprehensive and understandable assessment, the methodology used to extract information was based on setting up a specific framework along the following lines:

- General properties of the AMF that affect fire hazards
- Potential fire hazards during bulk transport
- Potential fire hazards during unloading to fleet storage
- Potential fire hazards during fleet storage

- Other safety hazards, particularly high pressure and low (cryogenic) temperatures that affect personnel safety
- Toxicity of the fuel based on inhalation, skin contact, and ingestion
- Environmental effects of spills on land or water

This same framework is used for the presentation on each AMF in Section 3.3 - Analysis of Issues. The information in this section represents a synthesis of the specific safety and health concerns derived from a relatively large number of documents.

Section 3.4 - Summary Assessment of Risk - provides a summary assessment of the safety, health, and environmental issues on a comparative basis. This assessment is intended to provide a broader understanding of the relative ranking of each AMF with regard to:

- the relative potential for an AMF leak or spill during bulk transport and storage operations; and

- the relative consequences of an AMF leak or spill in the context of safety, health, and environmental impacts.

3.3 ISSUES ASSOCIATED WITH BULK TRANSPORT AND STORAGE OF ALTERNATIVE FUELS

3.3.1 Methanol/Methanol Blends

General Description

Methanol or methyl alcohol is a clear colorless liquid that can be made from a variety of sources including coal and natural gas. All methanol used commercially in the United States is manufactured from natural gas because this is by far the most economical feedstock.

Often, methanol fuel is designated M-100 to identify it as essentially 100% pure methanol. A popular methanol blend composed of 85% methanol and 15% unleaded gasoline is designated as M-85. The addition of 15 percent unleaded gasoline increases both the name luminosity and the fuel volatility. The latter effect both increases the cold starting capability and also generally makes the vapors present in fuel tank ullage spaces too rich to be flammable.

Typically, M-85 is considered as an alternative fuel for light and medium duty gasoline (spark ignition) engine applications whereas M- 100 is typically used in heavy duty diesel (compression ignition) engine applications. M-85 is also used in the flexible fuel vehicle (FFV) application where such vehicles can operate on any mixture in proportions of M-85 and conventional unleaded gasoline.

3.3.1.1 Safety Issues

(a) General Properties Affecting Fire Hazards

The physical properties of methanol that affect fire hazards include its volatility, flash point temperature, range of flammability limits, autoignition temperature, and electrical conductivity. There are other properties of importance that affect the consequences or potential damage associated with a methanol (or any alternative fuel) fire. These include the bum rate of liquid pools, the heating value of the fuel, flame temperature, and thermal radiation emitted from the fire.

Section 3.3 of this report provides a relative comparison of the physical characteristics of each alternative fuel that affects the safety, health, or environmental effects associated with its use. In this section, the major physical characteristics that differentiate the hazards associated with each fuel are summarized.

One general physical characteristic that differentiates methanol from other fuels is its corrosive characteristics. Methanol is incompatible with several types of materials normally used in petroleum storage and transfer systems, including aluminum, magnesium, rubberized components, and some other types of gasket and sealing materials[1] Therefore it is necessary to take special precautions to ensure that methanol is transported or stored in containers and transfer lines that have been specifically selected for that purpose.

The other significant difference between methanol and other AMFs is that it is considered to be more toxic. However, exposure limits for inhalation of methanol vapor are only slightly lower than those for gasoline (200 ppm threshold limit value [TLV] for methanol vapor; 300 ppm for gasoline vapor)[2] Since gasoline is much more volatile than methanol, it is likely that more gasoline vapors will be generated for an equivalent spill volume and therefore are more likely to be hazardous to the persons exposed.

NFPA 325M - Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids, 1991 Edition provides a Health Hazard Rating that provides an assessment of exposure risks for fire fighters. Methanol, along with natural gas, gasoline, and propane, has a hazard degree of 1, which is a material that, on exposure, would cause irritation, but only minor residual injury and is considered as only slightly hazardous to health. All of the other AMFs have a hazard degree of 0 which means that under fire conditions, they offer no hazard beyond that of ordinary combustible material.

One other general property of methanol is the low flame luminosity of a pure (M-100) methanol fire. This makes it difficult to see the fire or even estimate its size, particularly if it occurs in bright daylight. The methanol blends (M-85) have increased visibility because the burning of the gasoline fraction produces some luminance[3]

One other property of interest is the relative vapor density of methanol compared to air; at 1. II, methanol vapor is heavier than air. Therefore the vapor will tend to accumulate at ground level or in low-lying areas such as maintenance pits[4] If the methanol vapor is not quickly dissipated through adequate ventilation, it will linger in the low-lying areas creating an increasing opportunity for exposure to an ignition source and a subsequent fire.

The addition of unleaded gasoline to methanol to create M-85 can improve the cold starting capabilities and increase the flame luminosity of the fuel. With regard to some of the key characteristics noted above, the presence of the gasoline can be expected to reduce the corrosivity of the M-85 compared to M-100, but it will also increase the toxic health hazards.'

(b) Fire Hazards During Transport

The bulk transport of methanol is usually done by a standard petroleum products tanker truck which carries approximately 10,000 gallons of fuel. From a fire hazard perspective, there is little discernible difference in the bulk transport of methanol compared to gasoline or diesel. There is no reason to expect that methanol transportation, in general, will be any more subject to leaks or spills than conventional gasoline or diesel transport. However, one specific issue that must be considered is the possible use of materials that may not be methanol compatible in the tanker truck. This could become a problem if there is a long-term exposure of methanol to seals and gaskets that may deteriorate and become subject to leaks.

One physical characteristic of methanol that is an important fire hazard consideration during both transport and storage is the combination of vapor pressure and flammability limits. For M-100, vapor/air mixtures are potentially flammable at volume concentrations ranging from 6.7 to 36 percent. In a fuel or storage tank, a methanol liquid temperature between 10°C to 43°C (approximately 50°F to 110°F) at standard atmospheric pressure will create a flammable vapor/air mixture.[4] Therefore any ullage space in a container or storage tank that is vented to the atmosphere will contain flammable vapor-air mixtures at normal ambient temperatures found in transport and storage operations.

This condition is different from the ullage space in a gasoline container or storage tank where the vapor concentration will be above the flammable limits range at normal temperature and pressure (i.e., too "rich"). In the case of diesel fuel, which is much less volatile than methanol, the vapor/air mixture in the headspace will generally be below the flammable limits (i.e., too "lean") at normal ambient temperatures.

Therefore, with methanol, it is extremely important to ensure that there are strong safeguards against any ignition sources inside the tank and that any vent lines or other openings have flame arrestors. Any fill lines must extend below the liquid methanol surface to provide a seal between any external ignition sources and the methanol/air vapor.

The transport of M-85, assuming that it is not blended on-site at the fleet operators facility, mitigates some of the problems noted above for M-100. In general, M-85 is quite similar to gasoline in its flammability characteristics because the fuel vapor is composed primarily of gasoline.[3] Under normal circumstances, the headspace in the container or Storage volume will contain a vapor/air mixture that is above the flammability limits concentration range, i.e., too rich to burn.

(c) Fire Hazards During Unloading to Fleet Storage

The transfer of methanol from the bulk transport tanker truck to fleet storage must take into account the fact that any vapor/air mixture that leaks during the transfer operation will create a flammable volume. In addition, any methanol spill will quickly vaporize and form flammable vapor/air mixtures. For this reason, it is essential that all hose connectors have mechanical locking features, vapor recovery devices be in place between the tanker truck and the fuel storage tank, and that grounding devices be provided to prevent static electrical discharges from taking place. As noted earlier, any vent lines should have spark arrestors and the fill line should extend to the bottom of the storage tank.

(d) Fire Hazards During Fleet Storage

Methanol fuel is typically stored in an underground tank that is sized to meet the needs of fleet operations. The installation must be designed to use methanol compatible materials to avoid long term degradation and leaks. Fuel storage tanks designed for diesel or gasoline use may not be methanol compatible.

The fire hazards associated with M-100 storage will be greater than for diesel fuel storage because it is a much more volatile fuel. A spill or leak of M-100 will create a much larger volume of flammable vapor/air mixture than an equivalent diesel spill. However, the fire hazards associated with methanol storage should be approximately the same as, or lower than, with gasoline storage. Gasoline is more volatile than methanol; however, the potential range of flammability limits for M-100 is much greater (6.7% to 36%) than for gasoline (1.4% to 7.6%). This means that, considering an equivalent spill or leak (volume) of fuel, there will be an increased probability that the methanol/air vapor will come in contact with an external ignition source when compared to gasoline.

It should be noted that the range of flammability limits for most AMFs are highly dependent upon the maximum temperature of the fuel. For example, if M-100 is only exposed to a maximum temperature of 22 C (70 F) it is only possible to reach a maximum volume concentration of approximately 13% methanol based on its equilibrium vapor pressure at 22 C and at atmospheric pressure. Therefore, the actual range of flammability limits for methanol may not be greater than the range for other AMFs.

The use of M-85 is primarily considered as an AMF for light and medium duty gasoline engines; therefore, it is appropriate to consider the fire hazards as being comparable to that of gasoline. In fact the volatility and flammability limits of M-85 are very similar to those for gasoline because the fuel vapors from the blend are composed primarily of gasoline. Therefore, all of the precautions that are normally associated with gasoline storage must be observed. These are primarily those that are designed to minimize the presence of any external ignition sources. In addition, the presence of methanol requires that the storage tank installation must be methanol compatible.

3.3.1.2 Health Issues

Exposure to methanol can occur through inhalation of vapor, or through ingestion or skin contact with the liquid fuel. The toxic effects of methanol are the same regardless of the means of exposure. Considering the fact that methanol is quite volatile, it is most likely that the typical route for exposure is through inhalation of methanol vapors.

Among the AMFs considered in this study, methanol vapor is considered the most toxic for inhalation exposure. The measure of fuel toxicity is the threshold limit value (TLV) for vapor exposure and it can be expressed in terms of either a time-weighted average (TWA) for an eight-hour workday or a 40-hour week, or as a short term exposure limit (STEL) expressing the maximum concentration allowable for a 15-minute exposure. For methanol vapor, the TLV-TWA value is 200 ppm, while the TLV-STEL value is 250 ppm.[2] Other AMF vapors have toxicity (TLV-TWA) concentration values that are at least five times higher. As noted earlier, none of the AMFs are considered to be serious health hazards by the NFPA based on potential exposure during fire fighting activities.

Interestingly, conventional gasoline has a TLV-TWA close to that of methanol (300 ppm versus 200 ppm) and it is more volatile. Therefore, the toxic exposure risks with both of these fuels are likely to be similar. Diesel fuel vapors are apparently much more toxic than either methanol or gasoline since the TLV-TWA value for kerosene (as a proxy for diesel fuel) is only 14 ppm.[2] Fortunately, diesel fuel is relatively non-volatile at normal ambient temperature, therefore vapor exposure is not a significant issue.

The health issues with M-85 are similar to M-100. Considering the relative vapor toxicity and volatility of both methanol and gasoline, M-85 must be considered in the same health hazards category as M-100.

Personnel involved in the bulk transport and storage of both M-85 and M-100 must be protected from exposure through proper design of tanks and transfer lines, selection of methanol compatible materials, use of personnel protection equipment, and proper training to avoid accidental exposure. Something as simple as a drain line for a fuel filter or a transfer hose for emptying fuel tanks can help to reduce exposure for the personnel working on the equipment.

3.3.1.3 Environmental Issues

The major environmental issues of concern with all liquid AMFs is a fuel spill, particularly a spill that reaches a sewer or drainage system. The release of flammable liquids into a sewer system is prohibited by *NFPA-30 - Flammable and Combustible Liquids Code*. One of the physical properties of methanol that affects fuel spills is its water solubility. Normally, fuel handling facilities that have an emergency drain connecting to a sewer will have a separator or clarifier to ensure that the fuel (gasoline or diesel) will not reach the sewer. This approach will not work with methanol since it is soluble in water and will pass directly through the separator. Methods for separating methanol from water exist but they are quite complex and costly. Therefore, the best approach is to ensure that any spills in a facility are absolutely prevented from entering any drain through the use of impoundment systems to contain the entire volume of any potential above ground spill. In a bulk transport situation there is obviously no way to provide such assurance for any type of liquid AMF.

Fortunately, methanol is quite volatile so that it will not persist for a long period of time when exposed to the environment. Methanol also biodegrades quickly.

3.3.2 Ethanol/Ethanol Blends

General Description

Ethanol is produced by the fermentation of plant sugars. Typically, it is produced in the United States from corn and other grain products, while some imported ethanol is produced from sugar cane. Like methanol, ethanol is a pure organic substance whose physical and chemical properties are invariant, unlike some other AMFs such as natural gas or propane which are mixtures of different hydrocarbon molecules with no standard or average composition.

Pure or neat ethanol (E-100) is rarely used for transportation applications because of the concern about intentional ingestion. In fact, ethanol for commercial or industrial use is always denatured (small amount of toxic substance added) to avoid the federal alcoholic beverage tax. Therefore, it is unlikely that ingestion would be a serious problem. For heavy duty diesel (compression ignition) engine applications, such as transit buses, two ethanol blends have been used:

- Ethanol E-95, composed of 95 percent ethanol and 5 percent unleaded gasoline.
- Ethanol E-93, composed of 93 percent ethanol, 5 percent methanol, and 2 percent kerosene.

Both blends have been used in Detroit Diesel heavy duty engines similar to the 23:1 high compression ratio engines developed for methanol. For light and medium duty gasoline (spark ignition) engine applications, the typical ethanol blend is 85% ethanol and 15% unleaded gasoline. This fuel is similar to M-85; therefore, it can be used in flexible fuel vehicles which can ignite any mixture composition of E-85 and unleaded gasoline.

3.3.2.1 Safety Issues

(a) General Properties Affecting Fire Hazards

The general properties of ethanol ($C_2 H_5 OH$) are relatively similar to those of methanol (CH3 OH). With respect to fire hazards, ethanol is less volatile than methanol (the Reid vapor pressure of ethanol is less than half that of methanol) and the range of flammability limits is smaller. On this basis alone, ethanol is safer than methanol. However, as pointed out above, there are relatively few situations where the ethanol will be in a pure form since it is usually used as either E-95 or E-85. With both ethanol and methanol blends, any fuel vapors will contain a substantial percentage of gasoline, therefore there would be very little difference in the flammability characteristics of the two fuels.[3]

There are other general physical characteristics of pure ethanol that are important from a safety perspective. While ethanol is less corrosive to metals, gaskets, and seals than methanol, it is still necessary to make sure that any container, transfer lines, and fittings are made from materials that are ethanol compatible. Ethanol vapor is much heavier than air (much more so than methanol) so that any vapor from a leak will move downwards and collect in low lying areas where it may linger as a flammable vapor/air mixture unless there is adequate ventilation. Fortunately ethanol, similar to gasoline, has a relatively low odor threshold such that personnel in the vicinity of a leak of E-100 or any blend should be able to rapidly detect it. As noted in Reference 2, there is considerable variation in the reported odor threshold data for various AMFs, particularly ethanol and methanol. Therefore, the detection of a leak of any AMF by odor is subject to a number of variables.

(b) Fire Hazards During Transport

The bulk transport of pure ethanol or ethanol blends by tanker truck will be subject to the same types of hazards as other bulk transportation of petroleum products. As long as the tanker truck container, lines, and fittings are constructed from ethanol compatible materials, there would be no reason to expect an increased rate of leaks or spills when compared to the equivalent volume of gasoline or diesel fuel transported.

As with M-100, the bulk transport and storage of E-100 will involve an ullage space vapor/air mixture that is in the flammable range at volume concentrations from 3.3 to 19%, corresponding to ethanol tank temperatures between 4°C and 46°C (approx. 40-115°F).[4] Therefore, stringent precautions have to be taken to avoid the possibility of ignition sources inside any container or tank containing E-100.

Ethanol blends, typically E-85, that are transported will exhibit volatility and flammability characteristics that are very similar to gasoline because the fuel vapors will be composed primarily of gasoline. As with methanol blends, the headspace vapor/air mixture for E-85 will be above the flammability limits concentration range.

(c) Fire Hazards During Unloading to Storage

The transfer of E-100 from bulk transport truck to fleet storage must take into account the volatility and flammability of any leaked or spilled fuel. The following precautions are necessary:

- hose connections with mechanical locking fasteners;
- vapor recovery devices; and
- grounding devices to prevent static electric discharge.

The unloading of E-100 and ethanol blends must be accomplished at the same level of safety standards as used for gasoline. These standards are spelled out in *NFPA30-Flammable and Combustible Liquids Code and NFPA30A-,Automotive and Marine Service Station Code*. These codes address fueling facility, storage, and handling requirements for all flammable and combustible liquids including both M-100 and E-100. It is of interest to note that the NFPA classification for gasoline, M-100, and E-100 is exactly the same (Class IB flammable liquids defined as those having closed-cup flash points below 23°C and having a boiling point at or above 38°C). This is an example of the need to consider the spectrum of fire hazard properties when considering AMFs because as discussed above, the ullage space hazards alone make the transport and transfer of E- 100 (and M-100) an increased fire hazard risk when compared to the blended fuels and gasoline.

(d) Fire Hazards During Fleet Storage

Ethanol fuel storage requires the selection of materials that will not degrade over the long term. Fuel tanks designed for diesel or gasoline use may not be ethanol compatible.

The safety precautions that must be taken with ethanol storage are similar to those for methanol and include:

- Positive prevention of ignition sources entering the storage space by providing such devices as spark arrestors in vent pipes, properly sized ground straps, and fill pipes extending to the bottom of the tank; and
- Prohibiting the placement of any pumps or other equipment within the storage tank that can create an ignition source.

All of the above requirements for the prevention of ignition sources, leaks and spills, and adequate provision for handling any leakage of spills when storing or handling ethanol (and any other NFPA-designated flammable or combustible liquids) are spelled out in great detail in the applicable NFPA codes. For example, typical ignition sources identified in NFPA30 include:

- open flames
- lightning
- hot surfaces
- radiant heat
- smoking
- cutting and welding
- spontaneous ignition
- frictional heat or sparks
- static electricity
- electrical sparks
- stray currents
- ovens, furnaces, heating equipment

Therefore, there is a very substantial base of experience in handling and storage of such flammable liquid AMFs, such as E-100, E-85, M-100, and M-85. The experience has been codified into the NFPA codes which are used by local regulatory authorities (or alternatively, the Uniform Fire Code which is used more often in the Western part of the U.S.). On the presumption that these codes are followed by the agencies involved in the bulk transport and storage of AMFs, in cooperation with local fire authorities, there is no reason to expect a greater incidence of fires in ethanol (or other AMF) storage situations then for a comparable number of gasoline storage facilities.

3.3.2.2 Health Issues

Ethanol is less toxic than methanol. The threshold limit value-time weighted average (TLV-TWA) concentration for ethanol vapor is 1,000 ppm compared to 200 ppm for methanol. Extensive skin exposure to ethanol can cause redness and irritation. Concern about intentional ingestion of ethanol by employees is mitigated by the fact that alcohols intended for industrial use must be denatured in order to avoid the federal alcoholic beverage tax. Denatured alcohol is ethanol that contains a small amount of a toxic substance such as methanol or gasoline, which cannot be removed easily by chemical or physical means. However, ethanol fuels have been widely advertised as food-based, so there may be confusion among some users concerning the denatured status of fuel ethanol.

3.3.2.3 Environmental Issues

The major environmental concern with ethanol is the same as for methanol; since it is water soluble, it is necessary to take stringent precautions in order to ensure that any ethanol spill does not reach a sewer or drainage system. These same precautions cannot be assured for the bulk fuel transport situation.

3.3.3 Compressed Natural Gas

3.3.3.1 General Description

Natural gas has been used as a vehicle fuel in the United States for several decades. Because of the residential and industrial use of natural gas, the industry has its own distribution system and supply network that is much more extensive than for any other liquid or gaseous AMF. The issues of bulk transport and storage are completely different from most of the other AMFs which are typically transported to fleet storage via tanker truck, unless the natural gas has been liquefied. (Liquefied Natural Gas [LNG] is presented in the next section.)

The typical fuel system for natural gas vehicles is one with highly compressed (typically 20 to 25 MPa or 3,000 to 3,600 psi) gas stored in high pressure cylinders on the vehicle. The containment of natural gas at such high pressures requires very strong storage tanks which are both heavy and relatively costly. This distinguishing feature of CNG is the one that has the most impact on safety issues.

CNG is generally produced on-site at a fleet fueling facility using compressors fed from a nearby natural gas pipeline in conjunction with some limited high pressure on-site storage. For example, with very large fleets, the preferred approach will involve direct fast fill from the compressor where the compressor flow rate is sufficient to fill a vehicle tank in less than

10 minutes. In order to accomplish this filling effectively, an intermediate high pressure storage tank with a volume of 3 to 4 times the vehicle fuel tank capacity is required.[5] For slow fill (overnight), there is no need for a large storage tank, a small buffer tank is sufficient.

3.3.3.2 Safety Issues

(a) General Properties Affecting Fire Hazards

Natural gas is a mixture of gases comprised primarily of methane with small amounts of ethane, propane, and butane. These heavier hydrocarbons (i.e., ethane, propane, and butane) tend to reduce the octane rating of natural gas. Therefore, the actual composition of the natural gas plays an important role in the performance of fleet vehicles. For the purposes of discussion in this report, the physical properties are based on the properties of the principal component, methane, unless otherwise specifically noted. The typical range of methane for pipeline natural gas in various parts of the country is from approximately 80% to 95%. The California Air Resources Board (CARB) has adopted specifications for natural gas as a vehicular fuel which require that the methane content be greater than 88%. Even with this type of specification, there is still considerable variation possible in the general physical properties of natural gas.

The physical properties of natural gas that affect safety include the autoignition temperature and the flammability limits range. The autoignition temperature (also known as ignition temperature) is the lowest temperature at which a substance will ignite through heat alone, without an additional spark or flame. The ignition temperature of natural gas varies with fuel composition, but it is always lower than that of pure methane. The estimated ignition temperature of natural gas is in the range from 450-500°C. The flammability limits range for natural gas is approximately 5% to 15% volume concentration.

More importantly, the leakage of compressed natural gas will immediately form a large gas/air mixture volume that is in the flammable range within a portion of the immediate area around the leak. A unit volume of CNG at 25 MPa psi will expand by approximately 200 times when released to the atmosphere. The ignition energy required is very small for virtually all of the AMF vapor/air mixtures being considered (in the range from approximately 0.15 to 0.30 millijoules)[2]. Therefore, the existence of a CNG leak creates an increased probability of exposure to a stray ignition source such as a static electric spark when compared to the leakage of an equivalent mass of an AMF that is expelled in a liquid form and vaporizes over a period of time.

Natural gas is colorless, tasteless, and relatively nontoxic. An odorant is added in such amounts to make the odor noticeable at 115 of the lower flammability limit of 5%. Thus, the odor threshold for CNG is approximately 10,000 ppm. Therefore, personnel in the vicinity of a natural gas leak will be able to detect the presence well before the gas has reached the flammable limit in the area adjacent to the person.

The most unique physical characteristic of CNG does not derive from the physical properties of methane, but from the fact that the gas is stored at an extremely high pressure for use as a vehicular fuel. The presence of material stored and transferred at pressures that far exceed the normal experience of most fleet operations personnel raises the standard of precaution and training required. Inadvertent opening of valves or loosening of fittings containing high pressure natural gas will not only lead to creation of a fire hazard, but can also result in the high velocity ejection of metal parts or fragments that could be lethal to nearby personnel.

The existence of the high pressure methane gas also leads to thermodynamic expansion considerations which have not been addressed thoroughly in prior studies of CNG safety. The rapid expansion of methane gas from a high pressure cylinder or transfer line leak to atmospheric pressure will inevitably result in a significant cooling effect which will result in a vapor cloud of very cold and dense gas. Conventional practice has been to assume that any leak of CNG will rise immediately due to the fact that methane at normal temperatures is lighter than air. Consequently, safety design practices have been focused on ceiling ventilation and detection of methane vapors. In fact, it is highly likely that any significant leakage from storage tanks and transfer lines will migrate down and fill in low lying areas as it is moved about by any wind or circulatory effects. Ultimately, the methane will warm up and rise (assuming a flammable mixture has not come into contact with an ignition source), but it is extremely difficult to estimate the time involved and the configuration of the flammable methane/air mixture during that time period.

(b) Fire Hazards During Transport

In most cases, the only "transport" issue involves the connection from the existing natural gas pipeline to the fleet operators compressor station. The local gas utility will typically work with the fleet operator to provide an underground supply delivering pipeline quality natural gas at pressures ranging from 5 to 50 psig. While this is a much lower pressure, there is still a significant potential for a massive gas release if there is some unauthorized digging or trenching at the connection line resulting in a line break, or in the event of an on-site accident resulting in a line rupture at the connection to the compressor station. One necessary provision is a rapid and positive means of shutting off the supply flow from the pipeline in the event of any type of leak in the supply line.

In some cases, natural gas is delivered to the fleet user in compressed form by means of a truck trailer containing compressed gas. This type of gas delivery may be used on a permanent basis for small users who cannot justify the cost of a compressor station, or on a temporary basis to users whose compressor station is unavailable.

In this case, issues arise concerning the crashworthiness of the trailer: while the gas cylinders themselves are robust, the valves and associated piping may be vulnerable. Also, it is possible that the tanks might be exposed to a gasoline- or diesel-fueled fire should the tractor trailer truck be involved in a traffic accident.

The use of the CNG delivery trailer also requires that flexible connections be made and broken in the course of each delivery. Experience shows that extra vigilance is necessary during truck loading and unloading because of the making and breaking of connections, possibility of leaking connections, possibility of truck movement when connected, etc.

(c) Fire Hazards During Transfer to Fleet Storage

In the case of CNG, the process involves the compression of the natural gas to the desired pressure (approximately 25 MPa, 3600 psi) and transfer to the storage tank systems. There are various approaches that can be used for the CNG storage depending upon whether a fast fill (i.e., approximately 9,000 SCF of gas transferred to a vehicle in less than 10 minutes) or a slow fill (many hours or overnight) approach is used. In either case, however, there is some limited storage involved at pressures from 20 or 25 MPa (slow fill) up to 35 MPa for fast fill operations.

Pipeline natural gas contains small amounts of nitrogen, carbon dioxide, hydrogen sulfide, and helium. The quantity of these contaminant gases can vary from zero to a few percent depending upon the source and seasonal effects. More importantly, the pipeline gas can contain water vapor in amounts up to 112 Mg/m^3 (7 lbs. per million cubic feet) of gas.

The carbon dioxide and hydrogen sulfide components of natural gas, in the presence of water, can be corrosive to carbon steel. The corrosive effect is increased by pressure. Since the pressure considered in CNG vehicle applications is so high, there is a real concern about excessive corrosion leading to the sudden explosive rupture of a container. NFPA 52 Compressed Natural Gas (CNG) Vehicular Fuel Systems, 1992 Edition provides that the gas quality in any pressurized system components handling CNG comply with the following specification:

- H^{2}S and soluble sulfides partial pressure .... 0.35 kPa, max
- Water vapor .... 112 mg/m^3(7.0 lb./MMSCF), max
- C0^2 partial pressure .... 48 kPa, max
- 0^2 ....0.5 volume %, max

The NFPA committee involved in developing the standard relied on field experience and research which led them to believe that if the water content is limited as specified above, the potential for corrosion problems is not a major concern. It should be noted that a water vapor content of 112 mg/m^3 amounts to a very small concentration of water vapors; therefore, natural gas at or below this level is quite dry. The federal government has taken a more conservative position due to the corrosion failure of a cylinder comprising one of several in a tube trailer in 1978. As a result, U.S. DOT has specified the composition of CNG being transported in interstate commerce. The limits for the corrosive components are very low, including an upper limit for water vapor set at 8 milligrams per cubic meter of gas.

The existence of this potential problem with the corrosive properties of natural gas makes it necessary to dry and treat the gas before high pressure storage whenever such corrosive constituents are in place. NFPA 52 also states that cast iron, plastic, galvanized aluminum, and copper alloys exceeding 70% copper are not approved for CNG service because these materials lack the necessary strength or resistance to corrosion required for CNG service.

In addition to the NFPA standard, the Society of Automotive Engineers has established *SAE J1616 Recommended Practice for Compressed Natural Gas Vehicle Fuel* with provisions intended to protect the interior of the fuel container, as well as other fuel system components, from corrosion.[6]

All of the above serves to point out that there is a substantial level of care which must be taken in the design and operation of high pressure CNG storage systems in order to avoid leaks or ruptures. In the event of a leak or rupture, the CNG fuel flow rate out of the storage tank or piping can be very high, and any ensuing fire (or explosion) will be likely to have a very high heat release rate. Compounding this problem is the difficulty of shutting off the CNG leak and extinguishing the fire.

(d) Fire Hazards During Storage

The amount of CNG that has to be stored at the fleet operator's facility is a function of the fill technique. For fast fill, the CNG storage volume should be at least 3 times (often up to 4 times) the individual fleet vehicle fuel tank volume. For a typical 40-foot bus, the fuel tanks would require approximately 250 kg. of CNG. This would mean a buffer storage capacity of approximately 750 to 1,000 kg. Compared to other AMFs, this storage volume is fairly small, thereby reducing the total potential fire and explosion impact of a massive rupture of the storage tank.

A slow fill system would have a much smaller buffer storage system because the compression system would typically be sized to handle the maximum number of vehicles to be fueled on an overnight basis.

In the unlikely event that a fleet operator decided to fast fill from a mobile CNG tube trailer truck, the amount of CNG stored on- site would increase substantially. If more than one trailer were present on the site, the total amount of CNG would be in the order of 6,000 kg (13,000 lb). The Environmental Protection Agency has recently (Federal Register, January 31, 1994, pp. 4478-4499) issued a Final Rule promulgating a list of regulated substances and thresholds required under Section 112(r) of the Clean Air Act, as amended. Methane is on the list of regulated flammable substances with a threshold quantity of 4550 kg (10,000 lb). A facility storing more than this threshold amount is subject to the development and submission of a Risk Management Plan (RMP) which includes a hazard assessment, a prevention program, and an emergency response program. The RMP requirement is in the rulemaking process currently; the proposed rule was published on October 20, 1993 (58 FR 54190).

This requirement is much more applicable to the storage of LNG, hydrogen, and propane where there is more likely to be more than 4550 kg (10,000 lb.) stored at a facility. This threshold quantity can easily be exceeded for AMFs used in medium to large fleet operations.

3.3.3.3 Health Issues

The principal constituents of natural gas, methane, ethane, and propane, are not considered to be toxic. The American Conference of Governmental Industrial Hygienists (ACGIH) considers those gases as simple asphyxiants, which are a health risk simply because they can displace oxygen in a closed environment. The Occupational Safety and Health Administration (OSHA) has set a time-weighted average (TWA) personal exposure limit (PEL) of 1,000 ppm for propane. A number of minor constituents of natural gas have ACGIH-listed threshold limit values (TLVs), including butane - 800 ppm, pentane - 600 ppm, hexane - 50 ppm, and heptane - 400 ppm. The effective TLV for an average natural gas composition, considering all of these limits, is about 10,500 ppm.[3]

The odor threshold of odorized natural gas is about 10,000 ppm. Therefore, it is unlikely that personnel will be unknowingly exposed to the TLV concentration since they can detect it by odor.

3.3.3.4 Environmental Issues

There are no significant environmental hazards associated with the accidental discharge of CNG.

3.3.4 <u>Liquefied Natural Gas</u>

3.3.4.1 General Description

Liquefied natural gas (LNG) is produced by cooling natural gas and purifying it to a desired methane content. The typical methane content is approximately 95% for the conventional LNG produced at a peak shaving plant. Peak shaving involves the liquefaction of natural gas by utility companies during periods of low gas demand (summer) with subsequent regasification during peak demand (winter). It is relatively easy to remove the non-methane constituents of natural gas during liquefaction. Therefore, it has been possible for LNG suppliers to provide a highly purified form of LNG known as Refrigerated Liquid Methane (RLM) which is approximately 99% methane.

The primary advantage of LNG compared to CNG is that it can be stored at a relatively low pressure (20 to 150 psi) at about one- third the volume and one-third the weight of an equivalent CNG storage tank system. The big disadvantage is the need to deal with the storage and handling of a cryogenic (-160°C, -260°F) fluid through the entire process of bulk transport and transfer to fleet storage.

3.3.4.2 Safety Issues

(a) General Properties Affecting Fire Hazards

Even though the end product of the use of CNG and LNG for vehicular applications is essentially the same, the general properties affecting safety are quite different. On one hand, LNG is a more refined and consistent product with none of the problems associated with corrosive effects on tank storage associated with water vapor and other contaminants. On the other, the cryogenic temperature makes it extremely difficult or impossible to add an odorant. Therefore, with no natural odor of its own, there is no way for personnel to detect leaks unless the leak is sufficiently large to create a visible condensation cloud or localized frost formation. It is essential that methane gas detectors be placed in any area where LNG is being transferred or stored.

The cryogenic temperature associated with LNG systems creates a number of generalized safety considerations for bulk transfer and storage. Most importantly, LNG is a fuel that requires intensive monitoring and control because of the constant heating of the fuel which takes place due to the extreme temperature differential between ambient and LNG fuel temperatures. Even with highly insulated tanks, there will always be a continuous build up of internal pressure and a need to eventually use the fuel vapor or safely vent it to the atmosphere. When transferring LNG, considerable care has to be taken to cool down the transfer lines in order to avoid excessive amounts of vapor from being formed.

The constant vaporization of the fuel also has an interesting effect on the properties of the fuel, unless it is a highly purified form of LNG, i.e., RLM. The methane in the fuel will boil off before some of the other hydrocarbon components such as propane and butane. Therefore, if LNG is stored over an extensive period of time without withdrawal and replenishment the methane content will continuously decrease and the actual physical characteristics of the fuel will change to some extent. This is known as "weathering" of the fuel. 7

Another consideration is that under low temperatures, many materials undergo changes in their strength characteristics making them potentially unsafe for their intended use. For example, materials such as carbon steel lose ductility at low temperature, and materials such as rubber and some plastics have a drastically reduced ductility and impact strength such that they will shatter when dropped.

As before, many of these potential issues have been identified and addressed in the various codes that have been developed by the NFPA and under the Uniform Fire Code. For example, the NFPA has the following national standards and codes applicable to LNG:

- NFPA 59A - Standard for Production, Storage, and Handling of Liquefied Natural Gas
- NFPA 57 (draft) - Standard for Liquefied Natural Gas Vehicular Fuel Systems (*final code expected to be published in 1995*)

(b) Fire Hazards During Transport

LNG may either be liquefied on-site or it can be delivered to fleet storage using a standard 10,000 gallon LNG tanker truck. In general, only the largest fleet operators would find on-site liquefaction to be advantageous. Typical LNG storage vessels, including those used on the tanker truck, have the following basic components:

- <u>INNER PRESSURE VESSEL</u> made from nickel steel or aluminum alloys exhibiting high strength characteristics under cryogenic temperatures
- Several inches of <u>INSULATION</u> in a vacuum environment between the outer jacket and the inner pressure vessel. Stationary tanks often use finely ground perlite powder, while portable tanks often use aluminized mylar super-insulation.
- <u>OUTER VESSEL</u> made of carbon steel and not normally exposed to cryogenic temperatures
- <u>CONTROL EQUIPMENT</u> consisting of loading and unloading equipment (piping, valves, gages, pump, etc.) and safety equipment (pressure relief valve, burst disk, gas detectors, safety shut off valves, etc.)

The double walled construction of the LNG tanker truck is inherently more robust than the equivalent tanker truck design for transport of other liquid AMFs. Therefore, the transport of LNG is safer from the perspective of fuel spills resulting from a tank rupture during an accident. A rupture of the outer vessel would cause the loss of insulation and result in an increased venting of LNG vapor. While this is of concern, it is relatively minor compared to the prospect of an LNG spill.

An explosion of an LNG container is a highly unlikely event that is possible only if the pressure relief equipment or system fails completely or if there is some combination of an unusually high vaporization rate (due to loss of insulation) and some obstruction of the venting and pressure relief system preventing adequate vapor flow from the inner pressure vessel with a resultant pressure build up. If the pressure builds up to the point where the vessel bursts, the resulting explosion is known as a BLEVE (boiling liquid expanding vapor explosion) with the container pieces propelled outward at a very high velocity.[7] This is a highly unlikely event due to the extensive requirements for pressure relief including pressure relief valves and burst discs that are built into the design codes. (There have been no reports in the literature reviewed of any BLEVE occurring with LNG.)

In the event that the LNG vessel is ruptured in a transport accident and the LNG is spilled, there will be a high probability of a fire because a flammable natural gas vapor/air mixture will be formed immediately in the vicinity of the LNG pool. In an accident situation, there is a high likelihood of ignition sources due to either electrical sparking, hot surface, or possibly a fuel fire created from the tanker truck engine fuel or other vehicles involved in the accident. The vapor cloud from an LNG pool will be denser than the ambient air; therefore, it will tend to flow along the ground surface, dispersed by any prevailing winds.

When spilled along the ground or any other warm surface, LNG boils quickly and vaporizes. A high volume spill will cause a pool of LNG to accumulate and the boiling rate will decrease from an initial high value to a low value as the ground under the pool cools. The heat release rate from an LNG pool fire will be approximately 60% greater than that of a gasoline pool fire of equivalent size.

(c) Fire Hazards During Transfer to Fleet Storage

The transfer of LNG from a tanker truck to fleet storage is a complex process that involves the active participation of both the tanker truck driver and a representative of the fleet operator. A partial listing of some of the steps involved provides some indication of the safety precautions that are necessary.[7]

- After the truck is chocked and the engine is shut off, a grounding cable is attached to the truck to ground any electrostatic discharge.
- A flexible liquid transfer hose is attached to the tanker and purged with LNG to remove all air.
- A fleet operator representative will open the storage vessel liquid fill line and the driver will open the trailer's main liquid valve.
- The driver will control the pressure in the trailer tank via a pressure building line where LNG is vaporized and returned to the tank to maintain a pressure differential of at least 15 psi between the tanker and the storage vessel.
- The driver will use a mechanical means to maintain a tight connection at the hose coupler to compensate for differential expansion.

The safety features that are typical of truck storage transfer of LNG include equipment design such as trailer liquid valves that are interlocked with the truck brake system to prevent fuel transfer before the truck is properly secured; remote-controlled, redundant liquid valves; storage vessel alarms to prevent overfill; and long drain lines for safety-directing vented LNG vapor.

The complexity of the fuel transfer arrangement creates the potential for leaks and spills through human error and equipment failure. One of the particular concerns is that the fuel transfer equipment goes through a continuous cycle of cool down to cryogenic temperatures and warm up to ambient temperature. This type of thermal cooling can create additional stresses on equipment and sealing devices which could result in decreased reliability over time.

(d) Fire Hazards During Fleet Storage

LNG storage facility requirements for a total on-site storage capacity of 70,000 gallons or less are defined in the draft NFPA 57 - Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems. NFPA 59A - Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG) is applicable to storage volumes above 70,000 gallons. Both of these standards address similar issues including siting of the storage tank, provision for spill and leak control, and the basic design of the storage container and LNG transfer equipment.

One of the major provisions at any LNG storage facility is the requirement to provide an impounding area surrounding the container to minimize the possibility of accidental discharge of LNG from endangering adjoining property on important process equipment and structure, or reaching waterways. This requirement ensures that any size spill at a fleet storage facility will be fully contained and the risk of any fire damage will be minimized.

(e) Other Hazards

LNG has a unique safety hazard among the AMFs because of the potential exposure of personnel to cryogenic temperatures. Workers can receive cryogenic burns from direct body contact with cryogenic liquids, metals, and cold gas. Exposure to LNG or direct contact with metal at cryogenic temperatures can damage skin tissue more rapidly than when exposed to vapor. It is also possible for personnel to move away from the cold gas before injury.

The risk of cryogenic bums through accidental exposure can be reduced by the use of appropriate protective clothing. Depending upon the risk of exposure, this protection can range from loose fitting fire resistant gloves and full face shields to special extra protection multi-layer clothing.

Another unusual hazard associated with aged LNG will arise in the unlikely event that there is a large spill of LNG onto a body of water. This could occur in an accident situation involving an LNG transport vehicle container rupture and spill into an adjacent water body. The hazard is known as a rapid-phase transition (RPT) - in this case a rapid transformation from the liquid phase to vapor. If significant vaporization occurs in a short time period, the process can, and usually does, resemble an explosion.[8]

The RPT "explosion" phenomenon for LNG on water has been observed in a number of situations and has been studied extensively in both laboratory and large scale tests. The temperature of the water and the actual composition of the LNG are important factors in determining whether an RPT will take place. It should also be noted that RPTs have been obtained for pure liquefied propane with water temperature in the range of 55°C (I 30°F).

3.3.4.3 Health Issues

The principal constituents of natural gas, methane, ethane, and propane, are not considered to be toxic. The American Conference of Governmental Industrial Hygienists (ACGIH) considers those gases as simple asphyxiants, which are a health risk simply because they can displace oxygen in a closed environment. The Occupational Safety and Health Administration (OSHA) has set a time-weighted average (TWA) personal exposure limit (PEL) of 1,000 ppm for propane. A number of the minor constituents of natural gas have ACGIH listed threshold limit values (TLVs), including butane - 800 ppm, pentane - 600 ppm, hexane - 50 ppm, and heptane - 400 ppm. The effective TLV for an average natural gas composition, considering all of these limits, is about 10,500 PPM.[3]

Unlike CNG, LNG cannot be odorized; therefore, there is some concern about the ability of personnel to detect TLV concentrations. This is another reason to ensure that methane detectors are in place wherever personnel may be exposed.

3.3.4.4 Environmental Issues

There are no significant environmental hazards associated with the accidental discharge of LNG.

3.3.5 Propane

3.3.5.1 General Discussion

Propane, which is otherwise known as liquefied petroleum gas, consists of a mixture of propane, propylene, butane, and butene. These gases are referred to as natural gas liquids since they are present in wellhead natural gas. Liquefaction of these gases will occur by compressing them to pressures above 800 kPa (120 psi) at room temperature. The term propane is used in this section to reflect the fact that this AMF is typically composed of more than 95% propane. The term also reflects industry practice for the gas as a motor fuel.

Approximately 60% of the U.S. propane supply comes from the processing (stripping) of wellhead natural gas and the remaining 40% is a by-product of petroleum refining. Propane for use in vehicle fleet operations has to be formulated so that it contains at least 95% propane and contains no more than 2.5% butane and heavier hydrocarbons. ASTM specifications for propane meeting this requirement include those for commercial propane which is suitable for light duty internal combustion engine applications and special duty propane which is suitable for heavy duty applications.

There is a substantial base of experience with propane as an automotive fuel since it is the third most heavily used fuel, after gasoline and diesel fuel. It is estimated that there are approximately 350,000 propane vehicles in operation, with most of them being aftermarket conversions of gasoline vehicles. Historically, propane was used extensively in transit applications from the 1940s up to 1970. The largest single user was the Chicago Transit Authority which in 1970 operated 1,400 propane buses, reportedly with a good safety record.[5]

3.3.5.2 Safety Issues

(a) General Properties Affecting Fire Hazards

Propane is an extremely volatile fuel compared to the other liquid AMFs being considered. The Reid vapor pressure (RVP) of propane is more than an order of magnitude greater than gasoline which is the next most volatile fuel (1400 kPa versus 100 kPa). Propane is stored under moderate pressure (I 10 to 150 psi) at ambient temperatures to maintain it in a liquid state. In the event of an accidental release of propane to the atmosphere, about one-third of the liquid flashes to vapor at a temperature of -70~o~F or lower.5~ Leaking propane will discharge at a high velocity due to the pressure differential, turning the liquid into an atomized spray with the droplets typically evaporating before they can fall to the ground. Larger spill quantities will form a boiling pool on the ground surface which will cool down and essentially stop active boiling of the pool when the ground surface becomes sufficiently cool. Vaporization will continue until all of the propane evaporates.

Due to the rapid vaporization of propane, the pool bum rate is the highest of all the liquid AMFs considered. As a result, the heat release rate from a propane fire is approximately twice that of a gasoline fire for the same liquid spill volume. The flammability limits range for propane is similar to that for gasoline. Consequently, when compared to accidental spills of an equivalent volume of gasoline, propane vapor is more apt to come into contact with an ignition source due simply to the much higher volatility of the fuel and the resulting larger volume of flammable propane/air mixture.

Another physical characteristic of interest is that propane vapor is heavier than air so it will descend from the point of a leak and accumulate and linger in low-lying areas unless there is adequate ventilation.

(b) Fire Hazards During Transport

Propane fuel is typically delivered to fleet storage via tanker trucks with capacities up to approximately 10,000 gallons. All propane tanker trucks must conform to applicable U.S. DOT regulations regarding Hazardous Materials Regulations and Federal Motor Carrier Safety Regulations. The regulations specify the materials design factors and pressure relief considerations for cargo transport. A major concern is the setting of pressure relief valves so that the container will not vent propane vapor in the event of an unusually warm day. All of these containers are typically manufactured from steel and are qualified under the ASME pressure vessel code. The minimum design pressure for the container is based on the vapor pressure of the propane at 45°C (115°F). Since the vapor pressure for commercial propane at that temperature is 243 psig, the design pressure typically is 250 psig with a safety factor of 4:1, for the tank stress calculations and selection of tank construction materials.

These pressure requirements result in a very strong tank container design. The net effect is that the container for propane on a tanker truck will be much more rugged and resistant to rupture from mechanical forces associated with an accident when compared to the transport of other liquid AMFs that are not pressurized, with the exception of the double shell tank for LNG.

On the other hand, the transport of a liquid fuel at moderately high pressure means that there is an increased probability of fuel leaks at joints and fittings. The piping system including hoses, along with fittings and valves will all be designed to code requirements for the expected pressures. But with any piece of equipment that is in frequent use on the road, there is an increased likelihood of eventual wear and vibration that could create the opportunity for small leaks.

(c) Fire Hazards During Unloading to Fleet Storage

Propane is typically transferred from the tanker truck to fleet storage by pumping it from a truck into the storage container. As with any transfer of fuel, this is likely to be the most potentially hazardous part of the bulk transport to storage process. The fact that personnel are dealing with pressurized valves and lines, where any human error may result in a serious discharge of propane, makes it a point of concern.

Fortunately, propane is odorized so that the presence of a small leak may be detected by the presence of its odor in the vicinity of any personnel responsible for unloading it. However, as noted earlier, propane vapor will descend and in the absence of any circulating air, it may go undetected in a low-lying area.

(d) Fire Hazards During Storage

All propane storage containers are constructed according to the appropriate ASME Pressure Vessel Code. Design pressures are usually on the order of 250 psig with the pressure release devices typically set in the vicinity of 375 psig. Normally, underground tank installation is specified for liquid fuels such as gasoline and diesel, mainly because it eliminates the hazard of fuel spills caused by vehicles running into the tank, and also because it allows more space for parking of vehicles. Propane, however, is ordinarily stored in above-ground tanks constructed of thick guage steel. The tanks are strong enough to be supported by concrete or steel saddles without deforming. The tanks are then surrounded by heavy upright steel pipes structurally mounted in concrete to act as a barrier against vehicle intrusion into the tank area.[5]

The structural strength of the storage tank and the proper design of all piping, valves, and fittings should provide a high level of protection against any massive leaks. The weakest points in any pressurized system like a propane storage system will be at any joints, connections, or fittings where there are always possibilities for developing small leaks over time. The odorization of propane along with the proper placement of combustible gas detectors and the natural ventilation in an outdoor area should help to prevent any serious fire hazard from developing.

One of the major safety considerations with the storage of propane is the possibility of a pressure buildup in the tank due to external heating from a fire combined with a failure of the pressure relief or venting system. The resultant explosion of the tank due to overpressure would lead to a BLEVE incident. The fact that all of the applicable codes and federal regulations for container design provide for the placement of pressure relief devices, and the subsequent testing of those devices on a regular basis, leads to the conclusion that the likelihood of an overpressure leading to a BLEVE is exceedingly small, particularly in a fixed storage facility situation. Unlike an accident situation with a transport vehicle where it is possible to roll over and damage the pressure relief and other protective equipment, there is little reason to expect that multiple devices for pressure relief at a stationary facility would simultaneously fail.

(e) Other Hazards

Since propane is stored under pressure during bulk transport and storage operations, there is a potential hazard associated with an inadvertent opening of a fitting or plug which could become a projectile. In addition, when propane expands out of a leak or hole, the rapid vaporization or flashing of the liquid causes the stream to reach temperatures that can cause freeze bums.

When compared to other AMFs, the potential high pressure hazard with propane is much less than with CNG (3600 psi vs. 150 psi); and the freeze burn hazard is much less than with LNG, because the propane liquid starts at ambient temperature as it leaves the tank.

3.3.5.3 Health Issues

Since propane for fleet use is a mixture of hydrocarbons, the toxicity of the fuel is difficult to determine. The major constituent, pure propane, is considered to be a simple asphyxiant by the ACGIH and does not have an assigned TLV. The other significant, but much smaller, constituent is butane which has a TWA-TLV of 800 ppm. OSHA has set a PEL of 1000 ppm for propane, with the requirement that exposure to more than half this level requires that a medical monitoring program be instituted. Other than this OSHA requirement, there is no other agency or body that has established an exposure limit for propane.

It should also be noted that propane has been reported to contain a relatively high level of radon gas, with radon concentrations in propane that are well above current EPA guidelines for radon exposure.[9] Since the exposure of personnel to propane will be limited, the potential exposure to radon gas should not be a serious problem.

3.3.5.4 Environmental Issues

There are no significant environmental issues associated with the spill of propane, since the liquid will quickly vaporize.

3.3.6 Biodiesel

3.3.6.1 General Discussion

Biodiesel is an AMF that is derived from biological sources such as soybean oil, rapeseed oil, other vegetable oils, animal fats, or used cooking oil and fats. The chemical process for creating biodiesel involves mixing the oil with alcohol in the presence of a chemical catalyst such as sodium hydroxide. This process produces a "methyl ester" if methanol is used (typically the most common for economic reasons), or an "ethyl ester" if ethanol is used. In either case, the reaction also produces glycerin which is a valuable co-product. Either methyl ester or ethyl ester can be used neat (100%) or blended with conventional diesel ("petrodiesel") as a fuel for diesel (compression ignition) engines.

Current efforts to commercialize biodiesel in the United States were started by the National SoyDiesel Development Board (NSDB) in 1992. The emphasis of their activity is on the use of soybean oil methyl ester (SME) blended with petrodiesel at a 20% volume SME/80% petrodiesel (BD-20) and a 30%/70% blend (BD-30). These blends are believed to offer the best balance of cost and engine emissions characteristics. NSDB reports that as of the beginning of 1994, biodiesel had accumulated nearly eight million miles in demonstrations involving more than 1,500 vehicles in fleets across the country, particularly in urban buses.[10]

Methyl ester made from rapeseed oil (RME) is in widespread use in Europe due to a total or near-total exemption from fuel taxes in most EC countries. As a result, there is a much larger base of operating experience with biodiesel in Europe amounting to several hundred times more vehicles and miles than in the U.S.

3.3.6.2 Safety Issues

(a) General Properties Affecting Fire Hazards

Data for the properties of soybean oil methyl ester (SME) indicate that it is a safer fuel than diesel, which in turn, makes it safer than the other AMFs considered. For example, the flash point for SME is 218°C (425°F) compared to approximately 73°C (160°F) for the average No. 2 diesel fuel. It also has an extremely low vapor pressure, less than 1.3×10^{-5} kPa at 72°C. Therefore, when SME is blended with petrodiesel to create BD-20, the resultant flash point for the mixture is 118°C, still well above that for the petrodiesel alone.

Past experience with neat (100%) biodiesel has indicated that it is incompatible to immerse it with certain rubbers and plastics, but not with metals. Reports indicate that nitrile rubber and polyurethane-based compounds showed unacceptable deterioration while other elastomers such as SBR, butadiene, isoprene, hypalon, silicon, and polysulphide were not resistant to neat biodiesel. Acceptable replacement materials include fluorine - rubber (Viton A) and polypropylene- and polyethylene-based plastics[10] Therefore, the selection of materials to avoid degradation of seals, fittings, and hoses is important for biodiesel applications.

An unusual physical characteristic of blodiesel that has a fire hazard implication is the possibility of spontaneous combustion in highly unsaturated materials such as some vegetable oils and methyl ester which oxidize in the air. This is classically known as the "oily rag" problem where the rag is placed in a confined space, such as a pile in the corner, and there is no way for the generated heat of oxidation to dissipate. The higher temperature accelerates the oxidation process giving off even more heat until the pile of rags begins to smolder and then burn. Since oil-soaked rags or other materials such as filters in typical petrodiesel operations are not subject to spontaneous combustion, it will be necessary to alert personnel (e.g., at the fleet operator's fuel storage and maintenance facilities) of the potential for spontaneous combustion. This is not a serious problem and can be simply resolved by having closed metal cans for storing oil soaked rags and other oily combustible material.

(b) Fire Hazards During Transport

Due to the very low volatility and high flash point temperature of neat biodiesel and blends (BD-20, BD-30), there are no specific fire hazard problems during transport. Any leak or spill is less likely to ignite than diesel or gasoline under equivalent conditions. Biodiesel-compatible materials should be selected to avoid problems of degradation of seals and fittings.

(c) Fire Hazards During Unloading to Storage

There are no specific fire hazards. Unloading equipment should be designed to handle biodiesel to avoid any possibility of leaks.

(d) Fire Hazards During Fleet Storage

There are no specific fire hazards, other than the potential spontaneous combustion issue noted above.

3.3.6.3 Health Issues

Because there are essentially no vapors generated at normal transport and storage temperatures, pure or neat biodiesel can only be considered as a potential health hazard due to ingestion. Pure biodiesel looks and smells like a food product and could conceivably be ingested. If biodiesel were ingested, enzymes in the body would break the ester back into its original components, e.g., soybean oil and methanol.[11] This raises the potential issue of methanol toxicity as a potential health hazard associated with biodiesel. Consequently, biodiesel cannot be considered to be non-toxic, as often cited in the promotional literature.

3.3.6.4 Environmental Issues

Biodiesel is considered to be biodegradable based on the chemical nature of the materials. Test data indicates that biodiesel is in the same range as biodegradable soaps and detergents. Therefore there are no significant environmental hazards associated with biodiesel.

3.3.7 Hydrogen

3.3.7.1 General Description

Hydrogen is unique among AMFs because it cannot be produced directly, as in drilling a well for petroleum oil and natural gas. Hydrogen must be extracted chemically from hydrogen-rich materials such as natural gas, water, coal, or plant matter. A substantial quantity of hydrogen is produced each year in the U.S. - about 8.5 billion kilograms per year.

About 95% of the hydrogen in the U.S. is produced by steam reforming, a chemical process that makes hydrogen from a mixture of water and a hydrocarbon feedstock, such as natural gas. When steam and methane contained in the natural gas are combined at high pressure and temperature, a chemical reaction converts them into hydrogen and carbon dioxide. The overall energy efficiency of the process, i.e., the energy content of the hydrogen produced divided by the total energy (natural gas and energy used to run the reformer) consumed, is approximately 65%. Other techniques for producing hydrogen, including off-gas cleanup and electrolysis, are much more costly.

Over the long term, it may be possible to consider large scale electrolysis (passing an electrical current through water to split individual water molecules into hydrogen and oxygen) using sunlight on photovoltaic cells as the electrical power source, or some other renewable energy source such as wind power. Hydrogen obtained using this approach is termed "solar hydrogen" or "renewable hydrogen."

The actual use of hydrogen in automotive vehicles is limited to experimental and prototype vehicles. A number of prototype vehicles bum hydrogen directly using modified automotive engines. There are also a number of vehicles that use the hydrogen in a fuel cell to produce electrical power for electrical motor drives, i.e., a hydrogen powered electric vehicle.

In addition to the direct use of hydrogen there has been a demonstration program involving blends of up 15 percent in volume of hydrogen added to natural gas to create "hythane." In this case, the hydrogen provides up to 5 percent of the energy content of the blend.

3.3.7.2 Safety Issues

(a) General Properties Affecting Fire Hazards

Hydrogen is a difficult fuel to deal with because of its physical properties. One of these well known properties is that as a gas its density is very low - only 1/15th that of air. Therefore, for any practical applications, it is necessary to either compress the hydrogen or liquefy it. The problem with compressed gaseous hydrogen in a fleet vehicle application is the weight of the high pressure tanks. It has been estimated that the weight of the compressed hydrogen will only vary from 1 to 7% of the total weight of the tank. Fortunately, the energy density of hydrogen is very high so that I kg of hydrogen contains approximately 2.5 times more energy than 1 kg of natural gas. Therefore, assuming an equivalent engine efficiency, the weight of a vehicle's compressed hydrogen fuel storage system will be similar to that for a CNG fuel storage system. The alternatives to compressed hydrogen tanks on the vehicle include liquefied hydrogen, an on-board converter fueled by methanol to create hydrogen, and storage of hydrogen in metal hydride systems. All of these techniques are the subject of research.[12]

For bulk distribution of hydrogen, the most common method by far is to liquefy the hydrogen and transport it by truck trailers, barges, or railcars. At atmospheric pressure, liquid hydrogen (known as LH2) boils at -253°C (423°F), which is only about 20°C above absolute zero. The process of hydrogen liquefaction, storage, and distribution is challenging, to say the least.

Hydrogen is usually liquefied in a complex multi-stage process that involves the use of liquid nitrogen (boiling point of approximately -200°C). Special precautions are required during liquefaction to maintain the proportions of two types of hydrogen molecules in order to avoid excessive internal heating and vaporization while the LH_2 is being transported or in storage. LH_2 requires special insulation to maintain liquid conditions as long as possible. [12]

The physical property of hydrogen that creates the most significant fire hazard is the extremely wide range of flammability limits, i.e., from 4% to 75% by volume. This range is twice that of methanol which has the next widest range. In effect, any release of hydrogen into the air results in a much larger volume of a flammable mixture than an equivalent amount of any other AMF.

More importantly, the potential for an explosion or detonation of a flammable hydrogen-air mixture is very high. The ignition energy for hydrogen-air mixtures is much lower than for hydrocarbon-air mixtures. Very low energy sparks, such as from a static electric discharge, can lead to ignition; and if the burning gas is even slightly confined, the resulting pressure rise can lead to a detonation.

Among the other physical properties of hydrogen that are of interest is the propensity of the gas to leak more easily than other AMF gases due to the relatively small size of the hydrogen molecule. Since hydrogen gas is colorless and odorless, leaking hydrogen cannot be detected unless an odorant, or possibly a colorant, has been added to the gas. Addition of odorant or colorant would be very difficult to implement in situations requiring liquefaction of the hydrogen. To compound matters, the flame of burning hydrogen is invisible in daylight, therefore adding an extra safety concern for personnel working near hydrogen tanks or transfer lines. "

Finally, hydrogen will diffuse into steel and other metal and cause a phenomenon known as "hydrogen embrittlement." This is a serious concern in any situation involving storage or transfer of hydrogen gas under pressure. Proper material selection and technology is available to prevent embrittlement, but there may be situations where such precautions have not been taken due to some oversight or error.

(b) Fire Hazards During Transport

It is assumed that the typical bulk transport mechanism for hydrogen- to-fleet storage will be liquefied hydrogen (LH_2) delivered by a specialized tanker truck. Under such conditions, the situation is analogous to transport of LNG. The tanker truck for LH_2 has to be constructed similar to the double walled configuration for LNG, but with a very high level of insulation due to the fact that the LH_2 is much colder than LNG. Thus, the LH_2 tanker truck design is expected to be even more robust than an LNG tanker truck in an accident situation.

In the event of a loss of insulation due to an accident, the rate of LH_2 vaporization would increase rapidly. Provisions are made in the design of storage vessels for venting and pressure relief in order to avoid any rupture of the inner tank containing the LH_2. The potential for ignition of hydrogen gas that is vented out at a high rate (as the result of an accident or other incident that causes loss of insulation) is an obvious fire hazard.

The rupture of the inner vessel would lead to a massive spill of LH_2. This is a particularly troublesome scenario because a flammable hydrogen air mixture would be immediately formed in the vicinity of the LH_2 pool and would quickly form a much larger volume of flammable gas as hydrogen boils off from the pool. Since the hydrogen gas is cold, it will be relatively dense and may stay in proximity to the ground for some period of time. The ignition energy required to initiate a hydrogen/air fire is very low so that the probability of an ignition source within a large flammable gas cloud in the accident area is quite high.

Another major hazard with a spill of LH_2 is that contact between the LH_2 and air can result in condensation of air and its oxygen and nitrogen components. A mixture of hydrogen and liquid oxygen is potentially explosive even though the quantities involved are likely to be small."

(c) Fire Hazards During Transfer to Fleet Storage

The transfer of LH_2 from the tanker truck to fleet storage is a complex process similar to that of LNG. There is the potential for leaks and spills due to the number of steps that are involved combined with the possibility of human error. Some of these specific concerns, which have been cited in the discussion of LNG, include the thermal cycling of fuel transfer equipment leading to additional stress on connection equipment and sealing devices.

(d) Fire Hazards During Fleet Storage

The storage facility requirements for LH_2 are spelled out in NFPA 50 B Liquid Hydrogen Systems - Consumer Sites. This standard addresses siting of the storage tank, provisions for spill or leak control, and the basic design of the storage container and LH_2 transfer equipment.

As with LNG, it is necessary to insure that any accidental discharge does not endanger adjoining property or reach any waterways, particularly those connecting to covered drainage systems. This is accomplished by providing an impoundment area surrounding the container.

(e) Other Hazards

LH_2 is very dangerous to personnel because cryogenic burns will result from direct body contact with (1) the liquid; (2) metals at LH_2 cryogenic temperatures; and, to a lesser extent, (3) with the cold vapors.

3.3.7.3 Health Issues

Hydrogen is not considered to be toxic. However, it is a simple asphyxiant which is a health risk because it can displace oxygen in a closed environment.

3.3.7.4 Environmental Issues

There are no significant environmental hazards associated with the accidental discharge of LH_2.

3.3.8 Electricity

3.3.8.1 General Description

Electricity can be considered as an AMF based on the use of electrically powered fleet vehicles using batteries as the energy storage medium. Most fleet applications currently considered involve vehicle tours that are relatively short and low speed, e.g., shuttle service, due to the limited range (less than 100 miles) and power of battery electric-powered vehicles. Typical battery recharging times are on the order of 6 to 8 hours requiring that fleet vehicles be recharged overnight. The current research focus for electric propulsion vehicles is in the area of battery development where the goal is to develop batteries that have low initial cost, high specific energy (Wh/kg), and high power density.

The bulk transport of electricity via the electric power distribution system is a fundamental part of the nation's infrastructure. The hazards associated with high voltage power lines, substation transformers, and local power distribution systems are well known. The National Electrical Code developed under the auspices of the NFPA covers the safety and protection measures associated with the provision of electrical service to the facilities.

3.3.8.2 Safety Issues

All of the safety issues associated with electricity are directly related to the transmission of electric power to the recharging station at the fleet facility. There is no storage issue since the electrical energy is stored in the on-board batteries.

The major safety concern is the exposure of personnel to electrical hazards as they work with the recharging system and connecting the vehicles to that system. This is not expected to be a serious safety hazard because the normal design practices for setting up the connections involve safeguards to ensure that personnel are protected from direct exposure to electrical hazards.

One of the safety advantages of electricity compared to the other AMFs is that all facility personnel are generally familiar with the hazards associated with electrical power. Therefore, personnel working with the recharging system can be expected to be aware of the dangers and follow the proper safety procedures.

3.3.8.3 Health Issues

There are no specific health hazards associated with the transmission and use of electricity at a fleet facility.

3.3.8.4 Environmental Issues

There are no specific environmental hazards associated with the transmission and use of electricity at a fleet facility.

3.4 ASSESSMENT OF ALTERNATIVE FUEL - BULK TRANSPORT, TRANSFER, AND FLEET STORAGE SAFETY RISKS

3.4.1 Introduction

The previous section provided a detailed discussion of the safety, health, and environmental issues associated with the bulk transport, unloading and transfer, and fleet storage issues associated with each individual AMF. In this section, the individual issues are combined with the intent of conducting a summary assessment. This assessment is divided into two parts:

- An assessment of the relative potential for AMF leakage or spills during bulk transport and storage operations; and
- An assessment of the consequences of a fuel spill or leak in the context of safety, health, and environmental risks.

In the absence of reliable statistical data on accidental releases of the various AMFs during bulk transport and storage, the following assessments are largely subjective. However, there are a number of physical and engineering principles that have been used as a guide in this assessment. Briefly, they are as follows.

1. The standard for assessment is based on both diesel and gasoline. These fuels are transported, handled, and stored at ambient temperatures and pressures and they are stable during long term storage.

2. The risk of a leak or spill increases as the transport and storage pressure of the AMF increases. Even with systems designed for high pressures, human errors, manufacturing defects, and material weaknesses are bound to take their toll.

3. The risk of a leak or spill increases as the amplitude and frequency of the temperature changes imposed on transport, transfer, and storage equipment is increased.

4. AMF storage systems that require active intervention (either automated or manual) in order to maintain the safety and quality of the fuel product are inherently more complex. Increased complexity leads to increased risk of leaks or spills through human error or mechanical/electrical failure.

3.4.2 Assessment of Relative Potential for Spills and Leaks

The first step in developing a summary assessment of bulk transport and storage risks is to examine the potential for accidental release of each AMF during each step in the transport and storage process. The following discussion considers the relative potential for accidental release based on the characteristics of each fuel and its transport and storage requirements.

Hydrogen is not considered in this part of the assessment because there are a number of potential issues regarding transport and storage modes that must be resolved through further research and development. For example, it may be determined that the best approach is to use methanol and reform it directly on the vehicle to create an on-board hydrogen source.

Electricity is not considered in any part of the assessment because it is completely different from the perspective of bulk transport and storage characteristics.

3.4.2.1 Bulk Transport

The major concern regarding accidental release during bulk transport is based on an accident scenario where the transport tank is damaged and a large amount of fuel is spilled. The possibility of leaks during transport is minimized by the selection of appropriate materials and proper design in accordance with the applicable material standards. Nonetheless, there are still fuel-related factors that would affect the relative potential for leaks. The ranking is presented in matrix format in Tables 3-1 and 3-2 for purposes of simplicity and convenience.

TABLE 3-1. RELATIVE POTENTIAL FOR SPILLS DURING TRANSPORT

AMF	RELATIVE SPILL POTENTIAL (COMPARED TO GASOLINE/ DIESEL TRUCK SPILL)	REASON
LNG	**Lower**	Double walled cryogenic transport tank
Propane	**Lower**	High pressure transport tank
Gasoline/Diesel	**Reference Fuels**	
Ethanol/Ethanol Blend	**Same**	Same tank structure as gasoline/diesel
Methanol/Methanol Blend	**Same**	Same tank structure as gasoline/diesel

TABLE 3-2 RELATIVE POTENTIAL FOR LEAKS DURING TRANSPORT

AMF	RELATIVE LEAK POTENTIAL (COMPARED TO GASOLINE/ DIESEL TANKER TRUCK)	REASON
Gasoline/Diesel	**Reference Fuels**	
Ethanol/Ethanol Blends	**Somewhat Higher**	Potential corrosion effects
Methanol/Methanol Blends	**Somewhat Higher**	Potential corrosion effects
Propane	**Higher**	Pressures up to 375 psi
LNG	**Higher**	300°F temperature differentials and pressures up to 150 psi

Tables 3-1 and 3-2 point out that the conditions which tend to create leaks (i.e., high pressure and temperature differentials) lead to bulk transport container designs that are more robust and less likely to be ruptured and spill the fuel cargo in an accident situation.

3.4.2.2 Unloading to Fleet Storage

The potential for spills and leaks during unloading operations is directly related to the pressure of the AMF, temperature differentials, and any corrosive characteristics of the fuel. The rationale for this statement is based on the observation that the existence of high pressure is more likely to lead to a massive rupture of material (e.g., transfer hose, flexible coupling) if it has been weakened by fatigue or temperature cycling, or if there is a material defect. A large temperature differential requires a more complex system to maintain control with increased possibilities for human error or equipment malfunction. The effects of corrosion on unloading equipment strength and integrity are an obvious concern.

CNG is treated as a special case in this study because the unloading to fleet storage consists of the process of taking pipeline quality gas, compressing it, purifying and drying it, and then maintaining a relatively small amount in storage prior to dispensing to the vehicle. The unloading process tends to be continuous during the time that fleet vehicles are being filled. The process is also highly automated and does not require direct personnel involvement such as that for tanker truck unloading, therefore reducing the opportunity for human error.

Considering all of the above, Tables 3-3 and 3-4 provide an assessment of the relative risk of spills and leaks during unloading operations.

3.4.2.3 Fleet Storage

The potential for spills and leaks during fleet storage is similar to that for the unloading of AMFs as noted in Tables 3-5 and 3-6.

3.4.3 Assessment of Safety Hazards

The assessment of safety hazards includes fire hazards, other hazards, health effects, and environmental effects. The most difficult area to assess is that of fire hazards because it comprises two parts:

- the likelihood that the vapor/air mixture from a leak or spill will ignite from a spark or other ignition source, including coming in contact with a heat source sufficient to raise the vapor to its autoignition temperature; and

- upon ignition, the relative safety hazard associated with the size and intensity of the ensuing fire or explosion.

The relative probability of ignition of an AMF leak or spill can be determined from the physical properties of the fuel and the physical requirements for transport and storage. The consequences of a fire or explosion depend upon the amount of fuel released. For the case of a massive spill, the volume of fuel stored becomes an important issue.

TABLE 3-3. RELATIVE POTENTIAL FOR SPILLS DURING UNLOADING

AMF	RELATIVE SPILL POTENTIAL (COMPARED TO GASOLINE/ DIESEL TRUCK SPILL)	REASON
Gasoline/Diesel	**Reference Fuels**	
Ethanol/Ethanol Blends	**Slightly Higher**	Potential corrosion effects
Methanol/Methanol Blends	**Somewhat Higher**	Potential corrosion effects
CNG	**Higher**	Pipeline gas corrosion effects and failure of high pressure (3600-5000 psi) transfer equipment
Propane	**Higher**	Combination of moderately high pressure (375 psi) and equipment failure
LNG	**Higher**	Combination of temperature cycling/mechanical failure and complexity of transfer process

TABLE 3-4. RELATIVE POTENTIAL FOR LEAKS DURING UNLOADING

AMF	RELATIVE LEAK POTENTIAL (COMPARED TO GASOLINE/ DIESEL TANKER TRUCK)	REASON
Gasoline/Diesel	**Reference Fuels**	
Ethanol/Ethanol Blends	**Slightly Higher**	Potential corrosion effects
Methanol/Methanol Blends	**Somewhat Higher**	Potential corrosion effects
Propane	**Higher**	Moderately high pressure
CNG	**Higher**	High pressure
LNG	**Higher**	Temperature differential and moderate pressure

TABLE 3-5. RELATIVE POTENTIAL FOR SPILLS DURING FLEET STORAGE

AMF	RELATIVE SPILL POTENTIAL (COMPARED TO GASOLINE/ DIESEL TRUCK)	REASON
Gasoline/Diesel	**Reference Fuels**	
Ethanol/Ethanol Blends	**Slightly Higher**	Potential corrosion effects
Methanol/Methanol Blends	**Somewhat Higher**	Potential corrosion effects
LNG	**Higher**	Moderately high pressure and equipment failure
Propane	**Higher**	High pressure and equipment failure
CNG	**Higher**	Complexity of container system to maintain cryogenic temperatures

TABLE 3-6. RELATIVE POTENTIAL FOR LEAKS DURING FLEET STORAGE

AMF	RELATIVE LEAK POTENTIAL (COMPARED TO GASOLINE/ DIESEL TRUCK)	REASON
Gasoline/Diesel	**Reference Fuels**	
Ethanol/Ethanol Blends	**Somewhat Higher**	Potential corrosion effects
Methanol/Methanol Blends	**Somewhat Higher**	Potential corrosion effects
LNG	**Higher**	Temperature differentials
Propane	**Higher**	Moderately high pressure
CNG	**Higher**	High pressure

For the case of bulk transport of liquid AMFs, the maximum typical volume of the standard fuel tanker truck is approximately the same - 10,000 gallons. Therefore, the hazards of a massive spill depend mostly upon the physical characteristics of the burning vapor/air mixture, the heat release rate and flame radiation levels. In the case of fleet storage, the approximation can be made that, for a fleet of equivalent size, the amount of fleet storage required is based on the energy density of the fuel. Assuming one unit mass (kg) of diesel fuel, the following equivalent amounts of fuel (as indicated in the left-hand box) are required to provide the same fleet miles, including engine fuel efficiency effects.

The size of a fire for a massive spill of the liquid AMFs will depend upon the volume of fuel spilled from a storage tank. Assuming a uniform unconfined depth for the liquid pool, the area will be directly proportional to the volume. Again, using diesel fuel as the reference, the box on the right indicates the relative volume of liquid fuel that must be stored to achieve the equivalent fleet miles.

Equivalent Fleet Miles – Mass

Diesel	1.00
CNG/LNG	1.15
Propane	1.15
Ethanol	1.90
Methanol	2.50

(Data from Reference 5)

Equivalent Fleet Miles - Volume

Diesel	1.0
Propane	1.9
Ethanol	2.1
LNG	2.3
Methanol	2.7

(Data from Reference 5)

It should be noted that total fleet storage capacity may require the use of several storage tanks. In that case, the maximum size of the fire from a spill would most likely be based on the capacity of a single tank.

The total potential exposure based on total storage capacity with most AMFs at the fleet operator's facility is approximately two to three times greater than diesel fuel based on the potential area of a liquid pool. The total fire hazard exposure would depend upon the highly unlikely event that all of the individual storage tanks would become involved in the course of an accident.

The only fuel not noted above is CNG. As discussed in Section 2, the fleet storage requirements for CNG will be quite small, on the order of 3 to 4 times the vehicle fuel capacity of an individual vehicle for fast fill operators. Therefore, for most CNG-fueled fleets, where the number of vehicles would be relatively large, the total heat release potential from a storage tank fire will be quite small compared to the other AMFs.

3.4.3.1 Potential for Ignition

In the event of a leak or spill, the physical properties of the AMF that have a direct impact on the potential for ignition include:

- FLASH POINT (applicable to fuels stored as a liquid) - at temperatures below this point, a liquid will not produce sufficient vapors to form an ignitable mixture with air near the surface of the liquid.

- FUEL VOLATILITY (applicable to fuels stored as a liquid at the referenced temperature) - measured by Reid vapor pressure, i.e., the pressure exerted by the vapor over the liquid in a closed container at 38 C (100 F).

- AUTOIGNITION TEMPERATURE - the minimum temperature required to cause self-sustained combustion in air due to heat alone, without any additional spark or flame. The autoignition temperature is also known as the self-ignition temperature, or simply the ignition temperature.

- FLAMMABILITY LIMITS - The range of fuel concentration in air, expressed as a volume percentage, that will support combustion. A concentration below the lower flammability limit will not propagate flame due to insufficient fuel, i.e., too "lean." A concentration above the upper flammability limit will not propagate flame due to an excess of fuels, i.e., too "rich."

- ELECTRICAL CONDUCTIVITY - the degree to which a fluid will conduct electricity measured in microsiemens per meter (us/m). Materials with lower conductivity are more likely to build up and experience static discharges due to sloshing (liquid fuels) or flowing.

In order to provide some perspective on these different properties for each of the AMFs, a series of figures have been prepared which illustrate the differences, and the effect on ignition potential.

Figure 3-1 shows the **flash point temperature** for all of the liquid AMFs. Propane and LNG are not shown because they are gases at ordinary temperatures and pressures. The figure illustrates the fact that diesel and soy-diesel are inherently much less prone to ignition because at normal temperatures, the liquid fuel is far below the flash point. Therefore, the spilled or leaked fuel would have to come in contact with a heat source in order to elevate the liquid temperature to the point where flammable vapor/air mixtures could be formed. Gasoline, on the other hand, will always be above the flash point; therefore, a spill or leak will immediately have a vapor/air mixture generated. Methanol and ethanol are less prone to ignition when the liquid temperature is quite cold, but once it gets above 10 C (50 F), flammable vapors will be generated.

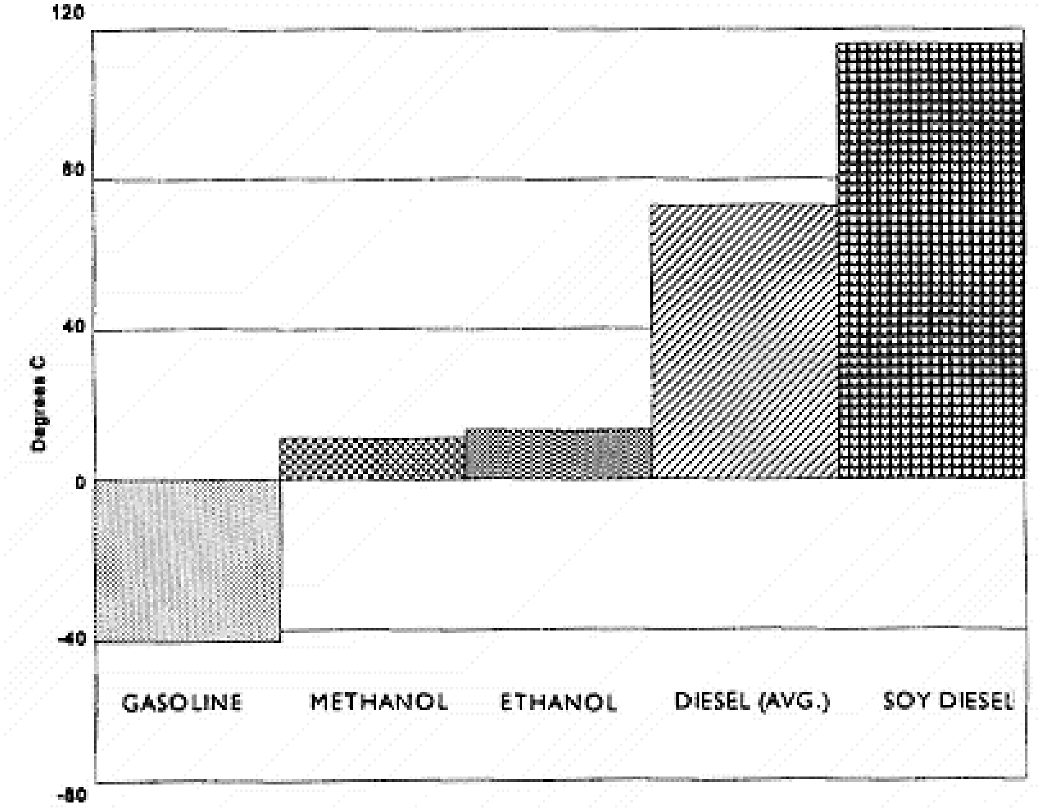


FIGURE 3-1. FLASH POINT TEMPERATURES FOR LIQUID AMFS

Figure 3-2 illustrates the **fuel volatility** for all of the liquid AMFs as measured by the Reid vapor pressure in kPa (6.9 kPa - 1 psia). As would be expected, the liquid fuel with the lowest flash point (gasoline) has the highest volatility. Propane is shown in this figure (not to scale) simply to illustrate the fact that it is extremely volatile, and upon release of this pressurized liquid, approximately one-third immediately flashes to vapor. Thus, a spill of propane is inherently much more prone to ignition than any of the other liquid fuels shown.

Figure 3-3 illustrates the **autoignition temperature** for a wide range of AMFs. It is of interest to note that in this case, the reference fuels, diesel and gasoline actually have the lowest autoignition temperatures. Fortunately, even for diesel which has the lowest autoignition temperature of those shown in the figure (230 C or approximately 450 F) the actual temperatures are quite high and not likely to be encountered unless a fire had already been initiated, or unless the fuel vapors came into direct contact with some very hot engine parts, e.g., the exhaust manifold.

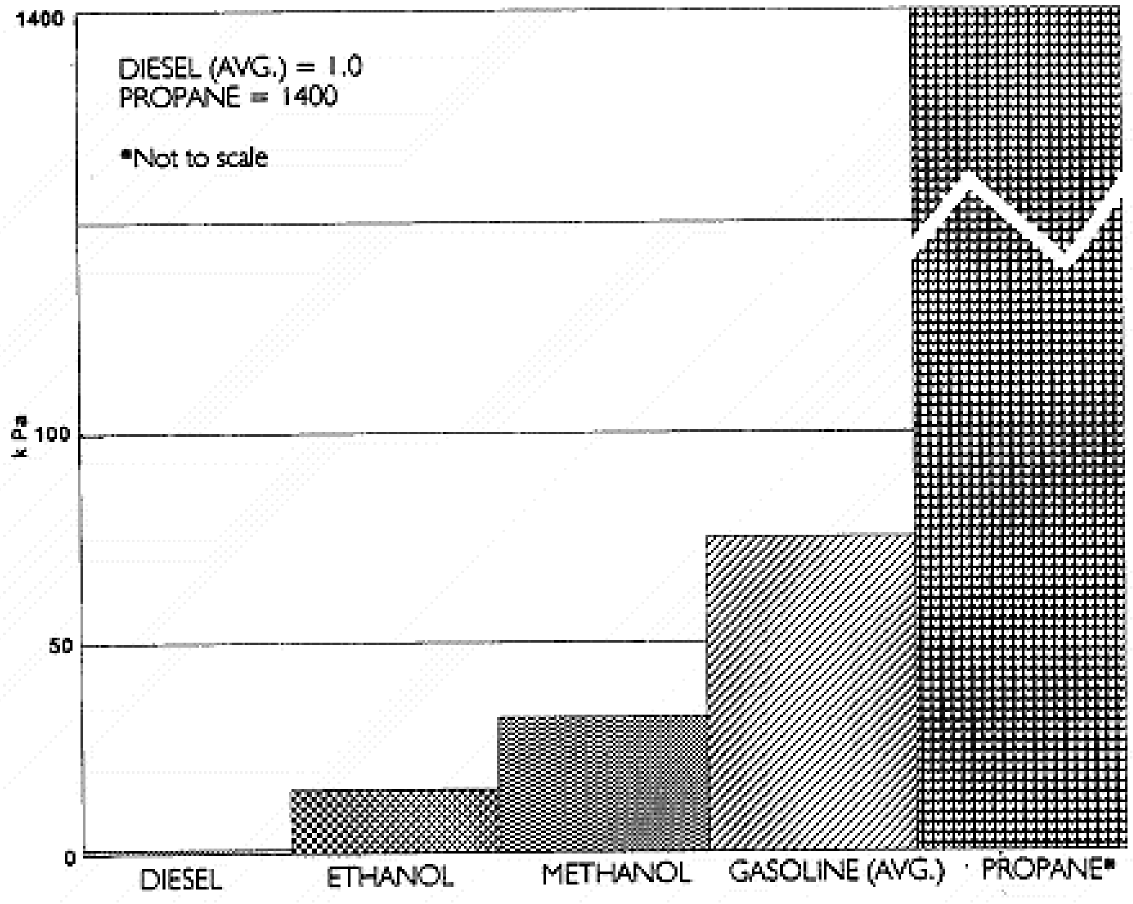


FIGURE 3-2. FUEL VOLATILITY — REID VAPOR PRESSURE (@ 38°C)

It is very important to remember that the values for propane and for methane shown in Figure 3-3 are for the pure gases. The AMFs, natural gas and vehicular propane, are variable mixtures of gases with autoignition temperatures that will be lower than the pure gas values shown. For example, natural gas is estimated to have an autoignition temperature range of 450-500°C, compared to the value of 540°C for pure methane.

Figure 3-4 shows the **flammability limits range** for a number of AMFs. This range is an important determinant of the likelihood of ignition. If the range is extremely wide, as it is for hydrogen, then the likelihood of encountering a flammable mixture is higher for a given volume of fuel because the total volume of the flammable mixture is much larger. Methanol, and to a lesser extent ethanol, also have fairly wide flammability limits; therefore, those fuels are much more prone to encountering an ignition source for a given volume of vapor than the other AMFs. In order to demonstrate the effect of temperature on the flammability limits range for ethanol and methanol, an intermediate line shows the maximum volume concentration that can be achieved for a normal temperature of 22°C (70°F). This line demonstrates that at this temperature, the "effective" flammability limits range for ethanol and methanol are equivalent to, or less than, most other AMFs.

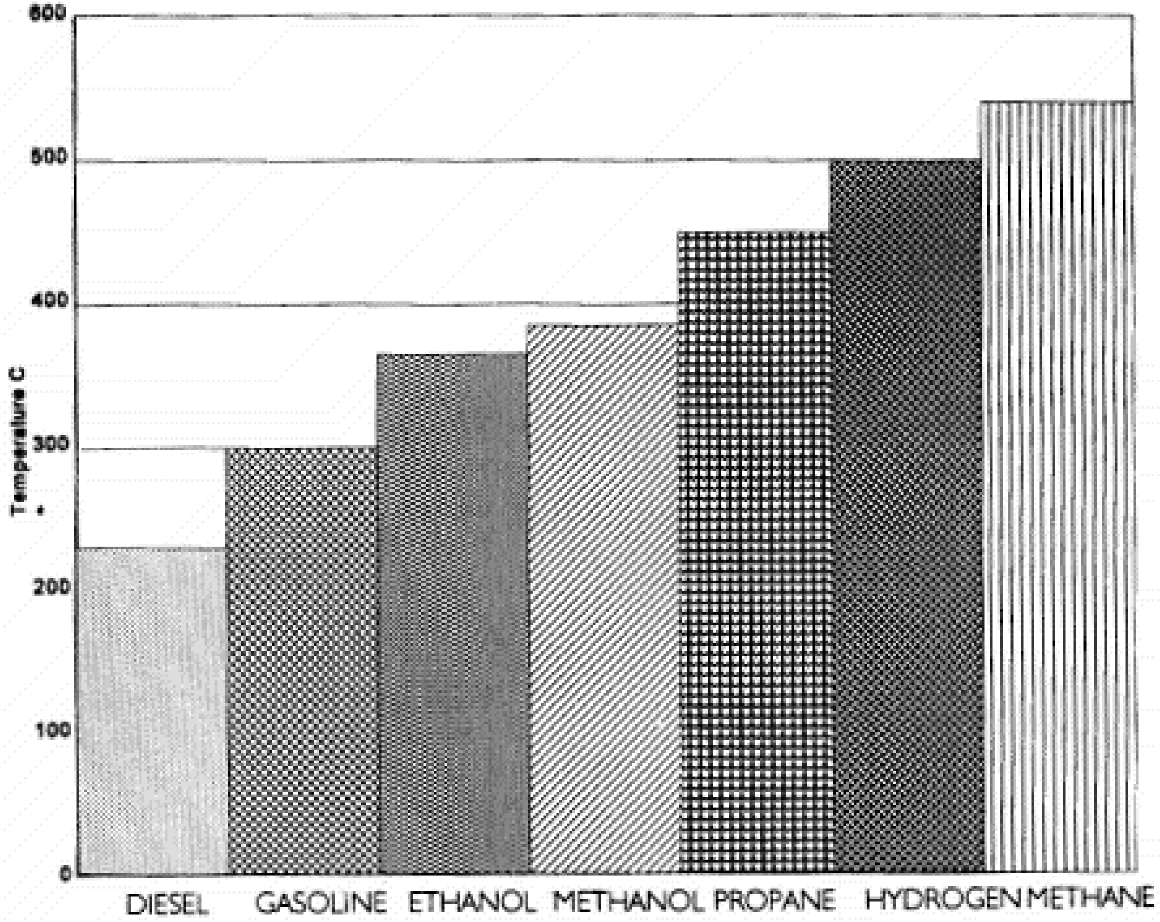
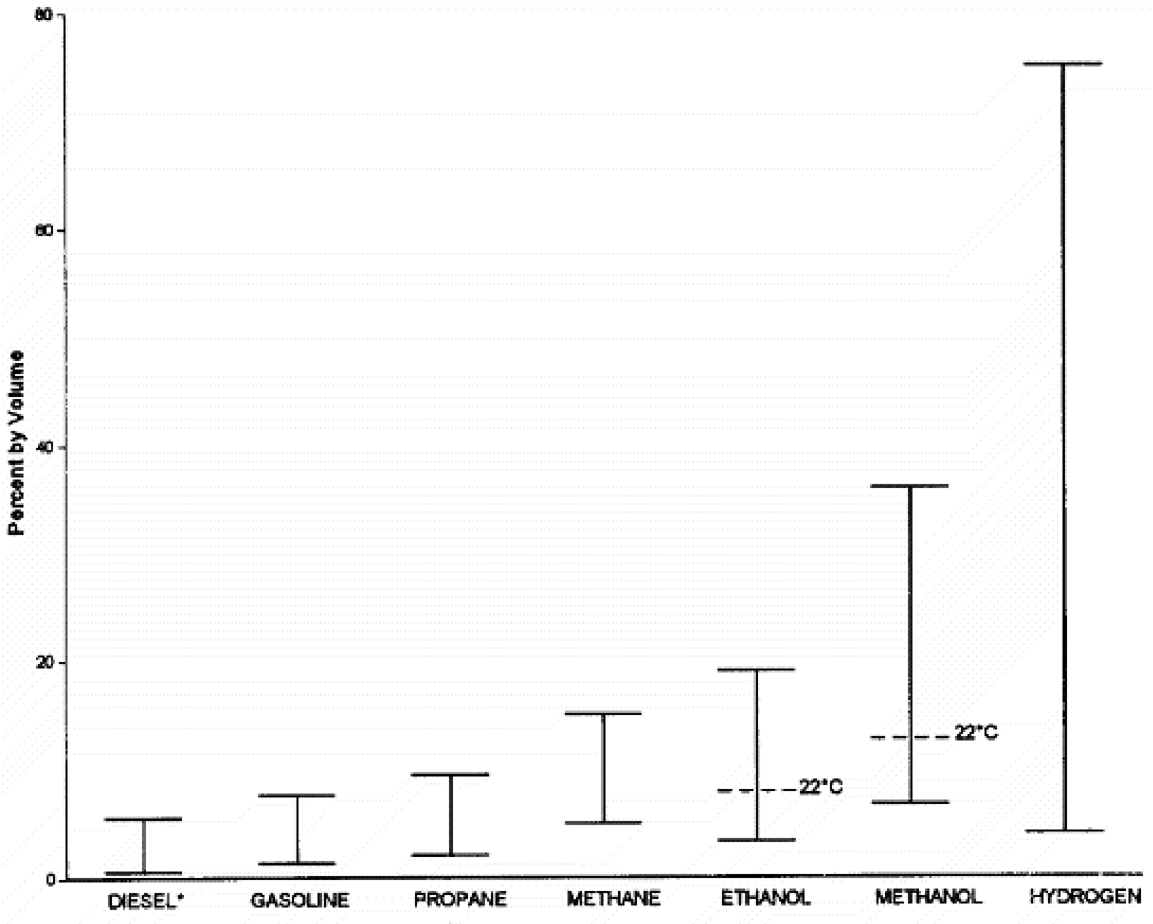


FIGURE 3-3. AUTOIGNITION TEMPERATURE

It is also necessary to note that ethanol and methanol are less volatile fuels such that it will take a longer time for a leak or spill of liquid to create the same volume of vapor, compared to the equivalent liquid volume of the more volatile fuels. If a leak of methanol or ethanol occurs at a liquid temperature well above the flash point, flammable vapors will be immediately formed and may linger in low lying areas. When compared to other heavier-than-air vapors such as propane, the wider flammability limits of ethanol and methanol create a higher probability of ignition under equivalent conditions.

The **electrical conductivity** of the fuel is important, as explained in the definitions of physical properties, in determining the effects of potential static electric discharges whenever fuels are in rapid movement such as the discharge from a high pressure tank or line. In most cases, adequate protection can be obtained by grounding the container or transfer line. However, there have been some situations reported where compressed natural gas, which is essentially non-conductive, escaping from a cylinder apparently ignited from a static electric discharge. The same type of phenomena may also develop with a high pressure leak of propane since the liquid fuel is quickly atomized while fuel flashes into vapor.



*only applicable at temperatures above 75°C (167°F)

FIGURE 3-4. FLAMMABILITY LIMITS RANGE

For the other liquid fuels, both gasoline and diesel have very low conductivities, with gasoline having a value of 1 x 10^{-6} µS/m and diesel having a value of 1 X 10^{-4} µS/m. Both methanol (44 µS/m) and ethanol (0.14 µS/m) have much higher electrical conductivities which will help to reduce static charge buildup. This is fortunate since both of these fuels in storage are likely to have ullage space vapor/air mixtures that are in the flammable range.

3.4.3.2 Consequences of Ignition

The major consequences of a fire include the damage within the fire area and the exposure of personnel and objects to thermal radiation outside the immediate area of the fire. There is also the possibility of the explosive or detonation type of burning of a vapor cloud which can cause an overpressure hazard.

The prediction of the actual consequences of the ignition of a leak or spill of an AMF is a very complex process because it is dependent upon so many different physical variables. For example, there are three basic scenarios for the burning of a liquid AMF.

- A pool fire in which a fire or fire plume is established on an evaporating (and burning) pool of the liquid.

- A vapor fire in which the ignition of an established plume (or cloud) of vapor results in the formation of a propagating fire.

- An explosive or detonation type of burning in a vapor cloud.

In order to consider the relative impact of AMF fires, it is obvious that the amount of fuel spilled is the most important factor. The size of potential spills during bulk transport and storage have been discussed previously in this section. The next consideration is the thermal radiation from fire.

A substantial amount of theoretical and experimental work has been accomplished on the subject of pool fires. Some of the experimental work included measurements of the thermal radiation from pool fires of LNG, propane, and kerosene (GRI, 1982).[14] As indicated in the box to the right, the relative thermal radiation (kW/M2) at the initial stages (first five minutes) of the fire normalized to kerosene (approximately 30 kW/M2) are as shown.

Relative Radiation Intensity Pool Fire

Kerosene	1.0
Propane	2.2
LNG	5.5

The reduced radiation intensity for propane and kerosene pool fires is attributed primarily to the soot that is generated with these fires which tends to mask the flames. Interestingly enough, these results do not extend to the case of a vapor cloud fire. Experimental results comparing the emissive power of LNG and propane cloud fires showed that they were essentially the same.[14] The comparative data for cloud and pool fires normalized to the emissive power of an LNG pool fire (in the range of 200 Mm2) is illustrated in the box to the right.

Comparison of Relative Pool and Cloud Fire Radiatoin Intensity

	Pool Fire	Cloud Fire
LNG	1.0	0.85
Propane	0.21	0.85

In most instances of an AMF spill, it is anticipated that with ignition, a pool fire will ensue. For this reason, an LNG fire is expected to be more hazardous than other AMF spill fires of equivalent volume occur-ring under similar weather conditions. However, since there are so many variables associated with predicting the size, shape, and thermal radiation effects of an AMF spill fire, it is not possible to make a relative assessment that would be valid for all conditions. It can simply be stated that on an overall (equivalent volume) basis, the ignition of either LNG or propane will have much greater consequences in terms of radiation intensity than that associated with other AMFs such as methanol/blends and ethanol/blends.

One other way to assess the potential consequences of an AMF spill fire is to consider the combustion energy released from a pool fire. There is some evidence to suggest that the fraction of combustion energy radiated from many types of hydrocarbon fuel fires including methane, natural gas, and propane is in the range of 20 to 25%. Therefore, some approximation of the overall radiative effects of a pool fire can be estimated from the heat release rate.

Figure 3-5 presents the **relative heat release rate** for liquid pool fires based on the mass rate at which liquid fuel is consumed per unit area and the heat content of the fuel. The heat release rate has been normalized to diesel, i.e., diesel pool fire heat release = 1.0. Since Figure 3-5 provides a comparison for pools of equal size, it provides an indication of the consequences of ignition of a complete spill of the contents of an AMF tank truck (assuming they all carry approximately 10,000 gallons) for all of the fuels shown. The figure clearly illustrates that the overall radiation effects resulting from a propane or LNG ignition and pool fire will be much more severe than that of an equivalent diesel spill. Conversely, the heat release and overall radiation effects from an ethanol or methanol spill fire will be a small fraction (approximately 25%) of that of the diesel fire.

One factor that is not shown in Figure 3-5 is the flame spread rate, i.e., the speed at which a flame will spread across the surface of a liquid pool of fuel. This could be an important factor in personal safety in that it defines the potential time that an individual has to move away from the pool. Based on limited data available, the flame spread rate for gasoline is the quickest at 4-6 meters/second (13-20 feet/second) while that for methanol is approximately 24 m/s (7-13 ft./s). A diesel pool fire, on the other hand, will spread very slowly at 0.02 0.08 m/s (0.8 - 3.2 inches/second)[2]. This is due to the fact that the diesel fuel will have to be heated up to its flash point before sufficient flammable vapor can be generated.

It is not as simple to characterize the heat release rate for CNG. The lowest flame speed (laminar burning velocity) for methane is approximately 0.4 m/s (1.3 ft./s). Any turbulence such as that caused by wind in the flammable gas mixtures will tend to dramatically increase the flame speed, therefore, it is likely that under most situations the flame will propagate very quickly with very little chance for personnel to react. Maximum flame speeds of approximately 10 to 15 m/s (33-50 ft./s) have been measured. One big problem with a CNG fire is that it is absolutely essential to cut off the CNG supply before attempting to extinguish it. Otherwise, there is the risk of another accumulation of flammable gas and subsequent reignition.

The consequences of ignition of a major spill at the fleet operator's facility will depend upon the volume of fuel stored. Using the volume equivalents to achieve the same energy equivalent mileage range for the fleet, as indicated earlier in the text, it will be necessary to store a greater volume of all liquid AMFs compared to diesel, ranging from 1.9 times for propane to 2.7 times for methanol. However, it is not possible to make a direct link between these increased volumes and increased fire hazards because the larger volumes are likely to be stored in separate tanks with appropriate separation and protection to avoid the spill fire from affecting adjacent tanks.

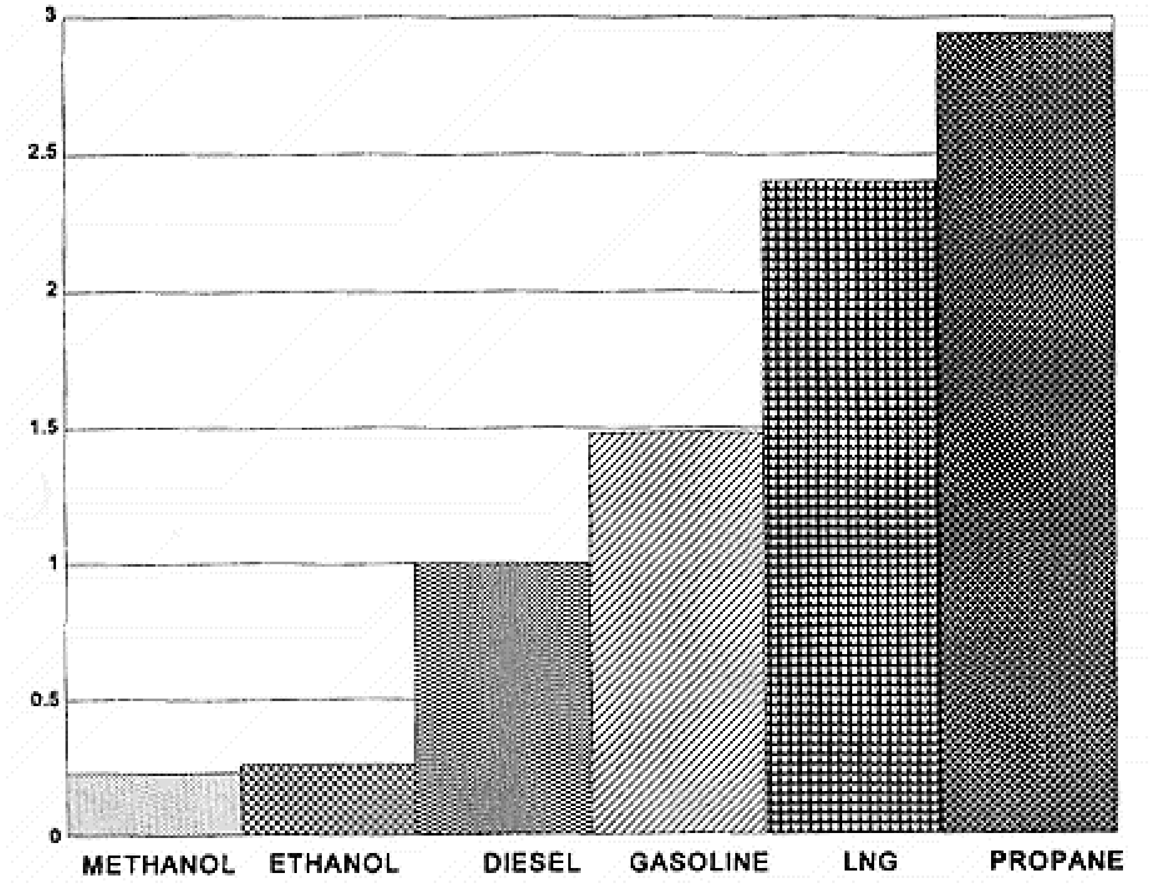


FIGURE 3-5. RELATIVE HEAT RELEASE RATE FOR LIQUID POOL FIRES

3.4.3.3 Other Hazards

This category includes the safety hazards associated with high pressures and low (cryogenic) temperatures. In terms of a relative assessment of the hazards for all of the AMFs considered (both primary and secondary); they can be ranked as follows:

High Pressure Hazards Ranking	**Low Temperature Hazards Ranking**
CNG	LNG
Propane	CNG
LNG	Propane
Methanol	Methanol
Ethanol	Ethanol
Biodiesel	Biodiesel

With regard to the high pressure hazard rankings, only CNG and propane are normally at sufficiently high pressure to cause problems with personnel safety for those working in close proximity. LNG is transported and stored at relatively low pressure but if there is some malfunction in the venting and pressure relief system, there is some possibility of a rapid pressure buildup due to thermal effects. The other AMFs are not subject to such pressure buildup.

Low temperature hazards are typically associated with LNG due to its cryogenic storage temperature. CNG and propane will become very cold when they expand from their respective storage pressures to atmospheric pressure; therefore, there is some low temperature hazard associated with these AMFs. The remaining fuels do not pose any problems with regard to low temperature hazards.

3.4.4 Assessment of Health Hazards

Most of the AMFs considered in this study are effectively non-toxic, particularly when they are compared to conventional fuels such as gasoline. The relative ranking of the AMFs on the basis of potential health hazards to personnel are indicated in the box to the right.

Potential Health Hazards to Personnel Relative Ranking

- Methanol/blends
- Ethanol/blends
- Propane
- Biodiesel
- CNG

Methanol and methanol blends are the most toxic AMFs for inhalation- exposure with a threshold limit value - time weight average (TLV- TWA) concentration value of 200 ppm. By comparison, the next lowest TLV-TWA concentration value for an AMF includes ethanol 1,000 ppm, followed by natural gas at a value of 10,500 ppm. In addition, there is an OSHA-SET personnel exposure time limit (PEL) of 1,000 ppm for propane.

The toxicity of the vapors should be considered in the context of the volatility of the fuel. For example, while gasoline has a higher TLV-TWA (300 ppm) than methanol, gasoline is also more volatile with a vapor pressure (RVP) approximately 2.3 times greater than methanol; therefore, personnel working in the presence of both of these fuels are more likely to be exposed to gasoline vapors than methanol vapors.

There is a similar concern with regard to an extremely volatile fuel such as propane which has a PEL of 1,000 ppm. Propane is generally required to be odorized such that a concentration of 1/5th of the lower flammable limit is detectable, i.e., approximately 4,200 ppm. Therefore, leaks of propane may result in concentrations of propane vapors that are well below the flammable limit and cannot be detected by odor, but still be in a concentration range that could reach the OSHA PEL value. By contrast, gasoline is detectable by odor at a concentration of 0.2 ppm; therefore, the same type of personnel health hazard does not apply to gasoline.

The reported data on odor detectability of methanol is not consistent, with values from 100 ppm to nearly 6,000 ppm cited in the literature. Assuming that an average value of 2,000 ppm is correct, it would be possible for personnel to be exposed to concentration values well above the TLV-TWA.

In all of these situations it is possible to use gas detectors (either fixed or portable) in areas where personnel are likely to be exposed to AMF vapors over an extended period of time. This would be an effective means of mitigating the potential health hazards associated with any particular AMF.

The ranking of biodiesel is based on the possibility of ingestion due to its vegetable oil appearance and odor. The human body will break down the biodiesel into its original components, e.g., soybean oil and methanol. This raises the potential of methanol toxicity depending upon the volume ingested.

3.4.5 Assessment of Environmental Hazards

The spill or leak of an AMF is not likely to result in any long term environmental damage. A review of the potential environmental hazards for each AMF, that is not gaseous at normal temperatures and pressures, shows that all of the liquid AMFs are biodegradable over a reasonably short period of time (i.e., a period of several months or less). The major concern is that the liquid AMF should be prevented from entering into any waterway or drainage system. Aside from any consideration of aquatic toxicity, there is actually a potential fire/explosion safety hazard situation created when a flammable or combustible liquid enters a waterway where there are covered sections where vapors can accumulate.

This above problem is particularly acute for the alcohols (methanol and ethanol) since they are soluble in water. Once such alcohol AMFs have mixed with water there is no simple and low cost method for separating them out. In a fixed facility situation, it is necessary to ensure that any AMF spill will not endanger any other portion of the facility or neighboring environs, and that they will not enter into any drainage system. This is achieved through various forms of impoundment systems (e.g., dikes) that are sized to handle any conceivable spill. During bulk transport, a spill can occur anywhere, including an area adjacent to a waterway or drainage system.

4. USE OF ALTERNATIVE FUELS BY VEHICLE FLEETS

4.1 INTRODUCTION

This section of the report is structured around a summary list or catalog of safety, fire, and health hazards (dangers) for each alternative fuel. In each instance, the assessment of the consequences of the hazards and of the state of knowledge concerning the hazards is based on a comparison to diesel or gasoline fuel as currently used by fleet operators and transit properties. This choice of a baseline was made to prevent the use of project resources to merely document safety knowledge that is generally available to and already practiced by transit and other fleet operators who use conventional gasoline- or diesel-fueled vehicles. Information for the summary list was derived from discussions with VNTSC, DOE and FTA staff, literature searches, telephone interviews, and site visits.

In order to place this summary list of hazards in context, the summary list is preceded by a discussion of the distinctions between hazardous fuel properties, hazards, and risks. The summary list of hazards is supplemented by case histories of actual incidents involving alternative motor fuels. These case histories, though anecdotal in natural, can serve to illustrate and extend the discussion of individual hazards.

In addition to organizing the substance of this part of the report, this summary list of hazards will provide a checklist for fleet operators who are considering alternative fuels and a guide to the state of knowledge and knowledge gaps concerning the various alternative fuels.

4.2 OBJECTIVES AND SCOPE

The objective of this section is to review and assess the hazards associated with the fleet use of alternative fuels for motor vehicle fleet operations, within the following scope limitations:

- This report does not cover hazards to the environment and is not an environmental assessment of alternative fuel use.

- The report is not a risk assessment and does not evaluate hazard probabilities, so there are no numerical ratings or rankings of fuels or hazards according to their overall risk.

Obviously, no list of hazards can be exhaustive. An attempt has been made to identify all major hazards and to choose and/or emphasize those fuel-hazard combinations which were judged to be most serious thereby focusing the available project resources on the most significant hazards, while still meeting the objective of providing an overall survey of each of the alternative fuels.

4.2.1 Fuels Included

In this report, safety, fire, and health hazards are reviewed for each of the following fuels listed below. The number designation is the same as that used in the Summary List of Alternative Fuel Hazards as found in Tables 4-1 to 4-8. These tables commence with 4-1(a) through 4-1(h) and continue on successively from 4-8(a) through 4-8(h) for each of the listed fuels and their hazardous properties.

1. Compressed natural gas (CNG)
2. Liquefied natural gas (LNG)
3. Propane
4. Methanol and methanol blends
5. Ethanol and ethanol blends
6. Biodiesel
7. Hydrogen
8. Electricity

The last two fuels, electricity and hydrogen have been given less emphasis because the use of these fuels is likely to be further in the future. Reformulated gasoline and reformulated diesel have not been included in the hazard list because they are so similar to fuels that are already in widespread use that no additional hazard issues were identified.

4.2.2 Hazardous Properties Included

For the review of hazards of alternative fuels, the following hazardous properties are considered:

(a) Flammability
(b) Corrosivity
(c) Toxicity (including asphyxiation)
(d) High pressure
(e) High temperature
(f) Cryogenic temperature
(g) Mechanical energy
(h) Electrical energy

Other hazards that are not included in this report:

- Vacuum
- Radiation (radioactivity)
- Etiologic (bacterial, viral, etc.)
- Shock sensitive materials
- Noise and vibration

This list is not an exhaustive list of all possible hazardous properties but rather those deemed to be most relevant to the use of alternative fuels in motor vehicles. For example, radioactive materials, shock-sensitive materials, and vacuums all present hazardous properties that can result in hazards, but these hazardous properties are not relevant in the context of alternative fueled vehicles.

Some hazardous properties in the list are relevant only in the context of certain alternative fuels or certain vehicle and/or fuel system designs. For example, some electric vehicles may have batteries whose electrolyte is at a high temperature. Thus, the high temperature hazardous property is relevant to this fuel, but not to other fuels which are stored and used at normal temperatures or even to other battery designs, such as lead-acid cells, which do not employ high temperatures.

4.2.3 Accident Events Included

The existence of these hazardous properties and their associated hazards is not sufficient to cause an accident. Some type of accident event is necessary before the hazard and the hazard consequences are realized. While the events which lead to accidents are many and varied, most such events can be classified into several broad categories:

Initial Events:

- Improper design
- Improper installation
- Improper repair

Operating Events:

- Structural failure from material failure (from corrosion, fatigue, or other causes)
- Loss of containment from material failure
- Operator error
- Traffic accident

4.3 SUMMARY LIST OF ALTERNATIVE FUEL HAZARDS FOR VEHICLE FLEET OPERATIONS

4.3.1 Overview of Alternative Fuel Hazards

A general discussion follows of hazards associated with each of the previously mentioned hazardous properties. All discussion is in the context of the use of alternative fuels by motor vehicles. The numbering of these hazards follows the numbering which is used in the subsequent Summary List of Alternate Fuel Hazards - Tables 4-1 through 48 (sections a-h).

4.3.2 Safety Hazards Considered

(a) Hazardous Property = Flammability

All conventional and alternative fuels are flammable. The flammability of these fuels may result in:

- A pooled fuel fire
- A fuel vapor fire
- An explosion (if the hot products of combustion are confined and prevented from freely expanding into the atmosphere)
- A BLEVE (boiling liquid expanding vapor explosion)
- Exposure to fire from other causes, e.g., vehicle fuel tank exposed to a vehicle electrical system fire

(b) Hazardous Property = Corrosivity

Most fuels are not particularly corrosive. However, some battery electrolytes are strongly acidic or strongly basic. Also, materials compatibility problems may result in fuel leaks that present a fire hazard. The corrosive nature of these substances may result in:

- Failure of vehicle structural components from loss of strength due to corrosion
- Fuel leaks due to failure of fuel system components
- Injuries due to chemical bums

(c) Hazardous Property = Toxicity

The toxic nature of some fuels may result in:

- Acute health effects from fuel vapor inhalation
- Chronic health effects from fuel vapor inhalation
- Health effects from absorption of fuel through the skin

Even for fuels that are non-toxic, the displacement of breathable air by a gaseous fuel may result in:

- Asphyxiation

Some fuels, such as ethanol and bio-diesel, are advertised to be derived from food crops. This may tempt some people to risk ingestion, even though both of these fuels are processed so as to make them toxic:

- Ingestion

(d) Hazardous Property = High Pressure

Pressure is defined as force per unit area. As many simple calculations and unfortunate experiences have shown, even a seemingly modest pressure over a modestly large area presents a large force. High pressure can result in:

- Pressure vessel rupture
- Components acting as projectiles during disassembly
- Reaction force from high-pressure jets

(e) Hazardous Property = High Temperature

The hazards associated with high temperatures are generally well- recognized:

- Loss of material strength
- Burn injuries from human exposure to high temperatures
- Possible fire initiation from the exposure of flammable materials to high temperatures

(f) Hazardous Property = Cryogenic Temperature

Cryogenic temperatures are generally regarded as those less than 150°C. The hazards of such low temperatures are both obvious and subtle:

- Cryogenic bum injuries from human exposure to low temperatures
- Structural failure due to stress from contraction of cooled components
- Structural failure of materials due to embrittlement at low temperatures

(g) Hazardous Property = Mechanical Energy

The hazardous property of mechanical energy indicates the kinetic energy of rapidly moving parts or the potential energy of a large mass at an elevation. The danger from kinetic energy increases with the mass of parts and with the velocity, either linear or rotational. The danger from potential energy increases with the mass and the height. The mechanical energy hazardous property can cause:

- Separation or fragmentation of moving parts
- Crushing or impact from falling parts

(h) Hazardous Property = Electrical Energy

Electricity presents a number of familiar hazards, especially electric shock. The severity of these hazards depends on both the voltage and current available. While current flow is the factor that causes the injury in electric shock, higher voltages lead to greater danger. In general, voltages in excess of 50 volts are considered potentially lethal.

- Electric shock injuries
- Fire from electrical shorts
- Possible health effects from electromagnetic radiation

4.4 SUMMARY LIST OF ALTERNATIVE FUEL HAZARDS

The summary list of alternative fuel hazards follows.

TABLE 4-1(A). COMPRESSED NATURAL GAS (CNG) – FLAMMABILITY

Hazard – Event	Background	Consequences	Knowledge
Fire – from gas supply pipeline leaks	Because of the economics of CNG compression, there is an incentive to use pipeline supply pressures to the compressor that are much higher than those normally used for local natural gas distribution. Therefore, some transit operations with CNG fleets have natural gas supplies of 200-400 psig or more on the property, whereas normal natural gas local distribution pressures seldom exceed 10-80 psig.	The high line pressure means that large amounts of fuel can be released quickly.	There is a substantial body of knowledge about corrosion and leak hazards of natural gas pipelines and such accidents are generally infrequent. However, heavy use of road salt may subject pipelines under bus traffic areas to a corrosive environment not normally seen in rural settings.
2-17 **Fire** – from damaged gas supply pipelines	Because of the economics of CNG compression, there is an incentive to use pipeline supply pressures to the compressor that are much higher than those normally used for natural gas distribution. Some transit operations with CNG fleets have natural gas supplies of 200-400 psig or more on the property. Any construction work on the premises can endanger that piping. Construction crews working on the premises may not expect this level of danger.	The high line pressure means that large amounts of fuel can be released quickly.	Since such high gas pressures are not often used in urban areas and seldom used on private property, there is little experience with damage potential. Contractors and others may not be prepared for the possibility of such releases within an urban area.
Fire – from gas metering equipment after vehicle collision damage	Because of the economics of CNG compression, there is an incentive to use pipeline supply pressures to the compressor that are much higher than those normally used for natural gas distribution. Some transit operations with CNG fleets have natural gas supplies of 200-400 psig or more on the property.	The high line pressure means that large amounts of fuel can be released quickly.	Engineering design for crash protection is reasonably well-known and can be applied to mitigate this hazard.

TABLE 4-1(A). COMPRESSED NATURAL GAS (CNG) -- FLAMMABILITY (cont.)

Hazard – Event	Background	Consequences	Knowledge
Fire – from leaking underground CNG piping to fueling island due to corrosion	Piping from the compressor to the dispenser has pressures of 3000-4000 psig. Such piping is often made of stainless steel. Although stainless steel resists many types of corrosion, some types of stainless steel are very susceptible to chloride corrosion. Of course, in cold climates, sodium chloride is commonly used as road salt.	The high line pressure means that large amounts of fuel can be released quickly.	Although high pressure gas piping is often made of stainless steel, there is little experience with this type of service over the long term. Most CNG facilities are just a few years old or less.
Fire – from gas dispensing equipment after vehicle collision damage	Piping from the compressor to the dispenser has pressures of 3000-4000 psig. While fueling island collisions may be rare, there is the potential to release large amounts of fuel.	The high line pressure means that large amounts of fuel can be released quickly.	Engineering design for crash protection is reasonably well-known and can be applied to mitigate this hazard.
Vehicle fire – from fuel system leaks due to poor design	The use of compressed natural gas fuel involves materials, components, and techniques which have not been generally used on motor vehicles. Often, production CNG vehicles differ significantly in design from "breadboard" prototypes previously used by gas utilities and others as demonstration CNG fleets.	Fires from liquid fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels, this limitation does not exist and large fires can develop quickly.	The design experience base for use of high pressure gaseous fuels on vehicles is still relatively small. Although CNG vehicles have been operating for a number of years, many were small volume conversions and the engineering experience gained was not necessarily transferred or transferrable to other installers.

TABLE 4-1(A). COMPRESSED NATURAL GAS (CNG) -- FLAMMABILITY (cont.)

Hazard -- Event	Background	Consequences	Knowledge
Vehicle fire -- from fuel system leaks due to improper installation	Many CNG vehicles are converted from other fuels. The experience and skill of those doing such conversions is highly variable. Examination of converted vehicles has shown examples of fuel lines in openings without grommets, fuel lines routed too close to the exhaust system, and CNG tanks that were too close to other components. Past experience has shown that not all of those personnel doing these conversions are familiar with the provisions of NFPA-52.	Fires from liquid fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels, this limitation does not exist and large fires can develop quickly.	The experience base for installations using high pressure gaseous fuels on any given type or model of vehicle is still relatively small. Although CNG vehicles have been operating for a number of years, many were small volume conversions of unique design and the engineering experience gained was not necessarily transferred or transferrable to larger fleets. Additional information on conversion kits for CNG is given in [1].
Vehicle fire -- from fuel system leaks due to component failure.	The use of compressed natural gas fuel involves materials and components which have not been generally used on motor vehicles. And new component designs may not prove reliable. An example, is the number (at least 50) of Mirada PRD[2] failures observed in transit bus fleets in 1993-1994. Each of these failures resulted in a major fuel release.	Fires from liquid fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels, this limitation does not exist and large fires can develop quickly.	An example of component failure is the PRD failures observed in CNG transit buses. An early review of natural gas vehicle safety concerns is given in. [3]
Vehicle fire -- from other than alternative fuel source	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts and eventually involve the vehicle fuel system.	A major vehicle fire is almost certain to cause the CNG tanks to vent through the thermal protection devices. This will cause a rapid release of natural gas fuel and will make the fire much more intense. Moreover, the natural gas supply may make extinguishment of the fire inadvisable.	To date, no CNG vehicles are know to have been involved in a vehicle fire whose origin was not in the fuel system. However, vehicle fires do occur and experience with natural gas in stationary applications indicates that the presence of a natural gas supply can exacerbate fire damage.

TABLE 4-1(A). COMPRESSED NATURAL GAS (CNG) -- FLAMMABILITY (cont.)

Hazard -- Event	Background	Consequences	Knowledge
Fire -- after drive-away during fueling	Properly designed break away connectors can prevent most large fuel releases. Also, many CNG vehicles have ignition interlocks that prevent the vehicle from starting while the fuel door is open. But these fittings and interlocks cannot protect against all drive-away scenarios. Static electricity may ignite such fuel releases. This scenario was the cause of a fire in Las Vegas which destroyed a transit bus.	Any large fire has the potential to destroy the vehicle and/or injure employees. In addition, a fueling island fire could put the fleet out of commission by preventing fueling.	One such fire has occurred in Las Vegas. The number of CNG transit bus drive-aways to date is probably small, perhaps less than a dozen, so it is difficult to extrapolate a rate of fire incidence. For typical diesel bus fleets of 200-300 buses, drive-aways occur about once a month.
Fire -- from static ignition of fuel tanks during venting	At least a dozen such fires have already occurred as CNG tanks were vented to the atmosphere. Static charges are more likely to build up where droplets or particles are contained in a high velocity gas stream. When compressed natural gas escapes, droplets may be formed from cooling and subsequent condensation of water or heavy hydrocarbons in the gas, or from entrained compressor oil.	Some of these fires have destroyed vehicles.	The properties of static electricity are generally well-known, but are not always applied by operators of alternative fuel fleets. The generation of static discharges from jets is discussed in (4).
Vehicle explosion -- from fuel system leaks	Transit buses have fairly large volume enclosed spaces, especially the passenger compartment. If these spaces fill with a flammable mixture, a significant explosion can occur.	When ignited, a confined natural gas-air mixture can produce pressures of up to 800 kPa -- far more than vehicle glass or body structures can withstand.	One such explosion has occurred, in an articulated transit bus under repair at Houston Metro. An analysis of fuel gas leakage into the interior of a vehicle is given in (5).
Building explosion -- from vehicle fuel system leaks	Such leaks can form a flammable zone inside vehicle storage and maintenance buildings and if ignited can cause building explosions and serious injuries. Experience to date suggests that fuel system leaks will be relatively frequent until the technology of CNG use on vehicles becomes more mature.	When ignited, a confined natural gas-air mixture can produce pressures of up to 800 kPa -- far more than vehicle structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	Though some fluid dynamic modeling of fuel system leaks has been done for FTA, there is a lack of experimental data on flammable plume behavior and also a lack of codes and standards to guide the design of buildings for this fuel.

TABLE 4-1(A). COMPRESSED NATURAL GAS (CNG) – FLAMMABILITY (cont.)

Hazard – Event	Background	Consequences	Knowledge
Building explosion – from vehicle PRD failure	Such leaks can form a large flammable zone inside vehicle storage and maintenance buildings and if ignited can cause building explosions and serious injuries. Experience to date suggests that PRD failures will be relatively frequent until the technology of CNG use on vehicles becomes more mature. PRD failures are different from other fuel system leaks in that the flow rate of escaping gas is quite large, often 1-2 kg/s.	When ignited, a confined natural gas-air mixture can produce pressures of up to 800 kPa – far more than building structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	Though some fluid dynamic modeling of fuel system leaks has been done for FTA, there is a lack of experimental data on flammable plume behavior and also a lack of codes and standards to guide the design of buildings for this fuel.

TABLE 4-1(B). COMPRESSED NATURAL GAS (CNG) – CORROSIVITY

Hazard – Event	Background	Consequences	Knowledge
Explosion – of vehicle fuel tank due to internal corrosion	While the hydrocarbon constituents of natural gas are relatively benign, several impurities must be controlled to prevent excessive internal tank corrosion. These include water and sulfur, arsenic, and mercury compounds. The specific requirements will depend on the materials of construction of the tank.	The amount of stored energy in a CNG fuel tank is substantial and the rate of energy release in case of tank rupture is high. Any pressure vessel explosion is potentially serious.	The knowledge of fuel quality needed for good tank performance is generally good. However, often little is known about the levels of impurities in the natural gas supply being used. The absence of a specification for natural gas delivered to the consumer exacerbates this situation. Some relevant information on natural gas impurities is given in (8).
Erosion – due to impurities in gas	While not strictly speaking corrosion, the effects of erosion are similar: a removal of material and a weakening of the strength of the component. Impurities which may be responsible include particulates, gas hydrates, and ice crystals.	CNG components are under high pressure and loss of strength could result in a serious sudden release of pressure.	To date, no pressure vessel or line is known to have failed to contain the pressure due to erosion. However, numerous problems have occurred with CNG fuel nozzles due to erosion by solid impurities in the fuel or by ice or gas hydrate crystals.

TABLE 4-1(C). COMPRESSED NATURAL GAS (CNG) -- TOXICITY

Hazard -- Event	Background	Consequences	Knowledge
Adverse health effects -- from exposure to natural gas	Although natural gas has a low order of toxicity, it is not non-toxic. Some higher hydrocarbons found in natural gas are neurotoxins. Natural gas may also contain benzene, arsenic,(7)(8) and heavy metals, such as mercury,(9) that are toxic.	Some higher hydrocarbons found in natural gas are neurotoxins. Chronic exposure to these compounds has caused health effects. However, the incidence of health effects in the natural gas industry is generally low.	Because the composition of natural gas is variable, accurate information on the minor constituents of natural gas is not always available.
Asphyxiation -- from displacement of air	Natural gas is lighter than air and can collect in vessels and equipment that are not top-ventilated. This can include some vehicle compartments as well as facilities. A person who enters an atmosphere lacking in oxygen can lose consciousness in as little as 20 seconds and may die in 3-4 minutes.	If a person does not receive fresh air quickly, serious injury can occur.	The causes and effects of asphyxiation are discussed in standard safety texts.(10)
Adverse health effects -- from indoor exposure to formaldehyde in vehicle exhaust	Incomplete combustion of methane produces formaldehyde, an irritant and a possible weak carcinogen. Due to combustion quenching, natural gas engines produce some formaldehyde emissions, especially when cold. Though catalytic converters can control formaldehyde, these are not effective during pull-out when engine and exhaust system are cold. Numerous transit facilities already have indoor air quality problems during pull-out and employees may be sensitive, both physically and politically to this issue.	Aldehydes are very irritating to the eyes, nose, and respiratory system. Excessive aldehyde levels have led to employee discomfort and complaints.	Measurements made by Battelle for FTA have shown that formaldehyde concentrations are higher in the vicinity of CNG buses during morning pull-out than during diesel buses.

TABLE 4-1(D). COMPRESSED NATURAL GAS (CNG) -- HIGH PRESSURE

Hazard – Event	Background	Consequences	Knowledge
Explosion -- from corrosion of vehicle fuel tank.	While CNG fuel tanks must meet rigorous standards, several fuel tanks have failed due to unforeseen environmental conditions. Both improper installation, mechanical damage from road debris, and chemical corrosion can cause tank failure. Stress corrosion cracking of the fiberglass overwrap has been implicated in two recent CNG tank failures.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	More information is needed about the chemical environment seen by CNG fuel tanks and the effects on the strength of the glass overwrap. Also, effective methods of inspection and testing are needed to insure that the strength of CNG tanks has not been degraded.
Explosion -- from mechanical damage to vehicle fuel tank.	While CNG fuel tanks must meet rigorous design standards, CNG fuel tanks have failed due to corrosion. Mechanical damage from road debris, improper installation, and use of incorrect mounting components can all cause tank failure. For example, adequate clearances are necessary around the CNG tank in order to prevent chafing.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	Tanks mounted in the undercarriage of the vehicle have been found to suffer frequent mechanical damage from road debris. And numerous instances of improper installation have been found in which other components could cause chafing of the tank. Although laboratory tests have been performed with CNG cylinders that have been deliberately damaged in some way, the kind of damage which road debris might cause is hard to predict. Information on inspection of tanks for damage is given in (11).
Explosion -- of pressure vessel explosion from failure of compressor to shut off.	Natural gas compressors are positive displacement machines. If the limit switch(s) fail to operate, the compressor can over-pressure the cascade or fuel tanks.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	No such incident has occurred in a CNG operation. However, limit failures have occurred in other industries. A HAZOP and/or FMEA analysis should be performed to explore the consequences of various component failures.

TABLE 4-1(D). COMPRESSED NATURAL GAS (CNG) – HIGH PRESSURE (cont.)

Hazard – Event	Background	Consequences	Knowledge
Missile damage – from flying about of parts during disassembly.	CNG fuel systems are under high pressure. Improper disassembly procedures or faulty pressure indications can cause parts to act as projectiles. Studies of projectile impacts have shown that the energy that could be imparted to standard fuel system fittings by CNG would be sufficient to cause the death of large laboratory test animals.	Although the projectiles may not be large or heavy, the close proximity of people increases the risk.	Such incidents have been reported in transit CNG operations. In some cases, faulty pressure gages led workers to erroneously believe the system was not under pressure.
Missile damage – from pressure gage failure.	Pressure gages are known to fail under pressure. While the hazard is largely controlled in stationary applications, the vehicle environment can be more severe and pressure gage failures may be expected to occur more frequently than in stationary applications.	Although the projectiles from a failed gage may not be large or heavy, the close proximity of people increases the risk.	Gage manufacturers generally include features to insure that any failure does not occur on the front of the gage. However, proper installation of the gage is necessary for those features to be effective. No such incident involving a CNG vehicle is known to date.
Flailing damage – from fueling hose failure.	CNG fueling hoses carry gas at high pressure. A broken hose will flail wildly if unrestrained. Excess flow devices may help, but due to the high fill rates required for fleet operations, the allowable flow rate must be relatively large.	Although the fueling hose may not be especially heavy, the necessary close proximity of people greatly increases the risk.	Good information about the frequency of hose failures in CNG service is not available. There has been one incident where a plugged vent hose on a vented nozzle ruptured and struck a fueler.

TABLE 4-1(E). COMPRESSED NATURAL GAS (CNG) -- HIGH TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Natural gas is not stored or used at high temperatures and does not present a significant high temperature hazard.	--	--

TABLE 4-1(F). COMPRESSED NATURAL GAS (CNG) -- CRYOGENIC TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
Injury -- from contact with cold components.	High pressure gas releases produce vigorous cooling due to expansion of the gas. Unlike cryogenic fuels which feature low temperatures, the low temperatures from CNG releases can be unexpected.	Personal injury due to frostbite can occur.	Release of CNG can produce temperatures of -100 C or less.

TABLE 4-1(G). COMPRESSED NATURAL GAS (CNG) -- MECHANICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
Missile damage -- and/or injury from catastrophic compressor failure.	Natural gas compressors are large rotating machines. Mechanical failure could produce flying fragments.	Damage or injury due to flying fragments. The fragments may sever gas or electric lines and generate additional hazards.	A number of compressor stations have experienced serious mechanical failures of compressor units, e.g., sheared head bolts. In the chemical process industry, the incidence of compressor failure has been estimated to be $2000/10^6$ hrs.
Falling hazard -- from handling of heavy fuel tanks.	CNG fuel tanks, particularly when grouped in racks, are heavier than conventional diesel fuel tanks. Equipment and procedures will have to be developed for handling these heavy components. Even in the absence of any need for repair, the tanks will need to be removed for inspection and recertification.	Failure to handle heavy fuel tanks adequately can cause personal injury and damage to the tanks.	Although a number of fleets operate CNG vehicles, the author is not aware of any refined system for handling CNG fuel tanks during routine maintenance. A number of fleets have plans to construct specialized tank handling equipment, but there is as yet no experience on the success of those plans.

TABLE 4-1(H). COMPRESSED NATURAL GAS (CNG) -- ELECTRICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
Electric shock -- from electrical supply to natural gas compressor stations.	Natural gas compressor stations require large prime movers. If these are electrically operated, the size of the motors needed requires high voltage and high current.	Electric shock can cause serious or fatal injuries.	The design and precautions necessary to handle electrical loads safely are well-developed. The National Electrical Code (NFPA-70) summarizes this knowledge.

TABLE 4-2(A). LIQUEFIED NATURAL GAS (LNG) -- FLAMMABILITY

Hazard – Event	**Background**	**Consequences**	**Knowledge**
Fire – from LNG dispensing equipment after vehicle collision damage	While fueling island collisions may be rare, there is the potential to release large amounts of fuel.	The rapid evaporation of LNG on warm surfaces means that large amounts of fuel vapor can be released quickly.	Design for crash protection is reasonably well-known and can be applied to LNG fueling dispensers to mitigate this hazard.
Fire – in LNG fuel storage facility	LNG fuel storage facilities must contain moderately large quantities of flammable liquefied gas if they are to fuel a large fleet. To date, these facilities are located above ground and are subject to various component failures. Elimination of all local sources of ignition is the key to safety since small leaks and venting of LNG are relatively common occurances.	A fire in the vicinity of an LNG storage tank can result in rapid venting of large amounts of fuel.	Numerous reviews of LNG facilities for gas utility peak-shaving plants have been made. One short general review is presented in a NIOSH report. (19)
Vehicle fire – from fuel system leaks due to poor design	The use of liquefied natural gas involves materials, components, and techniques which have not been generally used on motor vehicles. Production LNG vehicles will differ significantly in design from prototypes previously used by gas utilities and others as demonstration LNG fleets.	Fires from conventional fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels, this limitation does not exist and large fires can develop quickly.	The design experience base for use of natural gas fuel (LNG or CNG) on vehicles is still relatively small, especially for a given type of vehicle. The total number of LNG-fueled vehicles that have ever been in service in the world is probably fewer than 1000 vehicles.
Vehicle fire – from fuel system leaks due to improper installation.	Many natural gas vehicles are converted from other fuels. The experience and skill of those doing such conversions are highly variable.	LNG vehicle fuel systems are under relatively high pressure, 80 to 200 psig. Thus, any fuel leak can release relatively large amounts of fuel quickly.	As noted above, the design experience base for use of natural gas fuel on any given type of vehicle is still relatively small.

TABLE 4-2(A). LIQUEFIED NATURAL GAS (LNG) -- FLAMMABILITY (cont.)

Vehicle fire -- from fuel system leaks due to component failure.	The use of cryogenic fuels involves materials and components which have not been generally used on motor vehicles.	LNG vehicle fuel systems are under relatively high pressure, 60 to 200 psig. Thus, any fuel leak can release relatively large amounts of fuel quickly.	There is essentially no body of knowledge on the design of cryogenic components for motor vehicle service. The lessons learned on the limited LNG vehicle demonstrations to date have not been collected and codified in the literature for use by automotive engineers new to this fuel. Some data on the failure rates of components in stationary service is listed in. [13] Vehicle service is more severe and likely to result in higher failure rates.
Vehicle Fire -- from other than alternative fuel source.	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts, and eventually involve the vehicle fuel system.	Because of the low boiling point of LNG, a BLEVE of the LNG fuel tank is possible. More likely is rapid venting of natural gas.	To date, no LNG vehicles are known to have been involved in a vehicle fire whose origin was not in the fuel system. However, such vehicle fires do occur and experience with natural gas in stationary applications indicates that the presence of a pressurized natural gas supply can increase the severity of fire damage.
Fire -- after drive away during fueling.	Properly designed break away connectors can prevent most large fuel releases. But these fittings cannot protect against all drive-away scenarios. Some LNG vehicles have ignition interlocks to prevent the vehicle from being started with the fuel door open. Such interlocks can help reduce the frequency of drive-aways.	Any large fire has the potential to destroy the vehicle and/or injure employees. In addition, a fueling island fire could put the fleet out of commission by preventing fueling.	For typical diesel bus fleets of 200-300 buses, drive-aways occur about once a month. Experience with CNG fleets shows that drive-aways still occur. The frequency for LNG fleets is yet to be determined.

TABLE 4-2(A). LIQUEFIED NATURAL GAS (LNG) – FLAMMABILITY (cont.)

Vehicle explosion – from fuel system leaks.	Transit buses have fairly large volume enclosed spaces, especially the passenger compartment. If these spaces fill with a flammable mixture, a significant explosion can occur. One such explosion has occurred, a transit bus at Houston Metro.	When ignited, a confined natural gas-air mixture can produce pressures of up to 800 kPa – far more than vehicle windows or body structures can withstand.	One such explosion has occurred, in an articulated transit bus under repair at Houston Metro. Information on the efficacy of various common ignition sources is given in. (14)
Building explosion – from vehicle fuel system leaks	Such leaks can form a flammable zone inside vehicle storage and maintenance buildings and, if ignited, can cause building explosions and serious injuries. Experience to date suggests that fuel system leaks will be relatively frequent until the technology of natural gas vehicles becomes more mature. Since natural gas from LNG is not oderized, some leaks may go unnoticed.	When ignited, a confined natural gas-air mixture can produce pressures of up to 800 kPa – far more than building structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	Though some fluid dynamic modeling of CNG fuel system leaks has been done for FTA, and much modeling of outdoor LNG releases has been performed, there is a lack of data on LNG flammable plume behavior inside buildings. There is also a lack of codes and standards to guide the design of buildings for this fuel.
Building explosion – from vehicle tank venting.	If LNG vehicles are not operated frequently, pressure will build in the fuel tanks. Eventually such pressure will be vented through a pressure relief valve. Such gas releases can form a large flammable zone inside vehicle storage and maintenance buildings, and if, ignited can cause building explosions and serious injuries. Venting episodes may be relatively frequent until the experience base with LNG vehicles increases.	When ignited, a confined natural gas-air mixture can produce pressures of up to 800 kPa – far more than building structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	No study is available of the frequency of unanticipated indoor LNG venting in a large fleet. Current LNG vehicles must be used every 3-10 days to prevent venting.

TABLE 4-2(B). LIQUEFIED NATURAL GAS (LNG) -- CORROSIVITY

Hazard -- Event	Background	Consequences	Knowledge
Seal failures -- from lack of low temperature capability.	While LNG is not corrosive per se, its cryogenic properties can have deleterious effects on gaskets, o-rings, and other seals.	Seal failures usually result in fuel leaks. Such leaks can lead to fire, injury, and explosion hazards.	Experience to date with LNG equipment shows that fuel leaks are common. Seal failures have been observed on LNG fueling nozzles.

TABLE 4-2(C). LIQUEFIED NATURAL GAS (LNG) -- TOXICITY

Hazard -- Event	Background	Consequences	Knowledge
Asphyxiation -- from displacement of air.	LNG vapors are heavier than air and can collect in low areas and in vessels and equipment that are not well-ventilated. This can include some vehicle portions as well as facilities. Since LNG is not odorized, people entering the space may not be aware that gas is present.	If a person does not receive fresh air quickly, serious injury can occur.	The causes and effects of asphyxiation are discussed in standard safety texts.(9)
Adverse health effects -- from indoor exposure to formaldehyde in vehicle exhaust	Incomplete combustion of methane can produce formaldehyde, an irritant and a possible weak carcinogen. Though catalytic converters can control formaldehyde, these are not effective during pull-out when engine and exhaust system are cold. Numerous transit facilities already have indoor air quality problems during pull-out and employees may be sensitive, both physically and politically to this issue.	Aldehydes are very irritating to the eyes, nose, and respiratory system. Excessive aldehyde levels have led to employee discomfort and complaints.	Measurements made by Battelle for FTA have shown that formaldehyde concentrations are higher in the vicinity of CNG buses during morning pull-out than during diesel buses. Since LNG fleets have the same natural gas engine, they are expected to show a similar effect.

TABLE 4-2(D). LIQUEFIED NATURAL GAS (LNG) -- HIGH PRESSURE

Hazard -- Event	Background	Consequences	Knowledge
Explosion -- from corrosion of vehicle fuel tank.	While the pressure in LNG fuel tanks is not as high as in CNG tanks, they are still pressure vessels and contain energy in the form of gas maintained at pressure. Much more information is needed about the range of chemicals that may contact the fuel tanks and the possible corrosive effects. Such agents include road salt, pressure washing detergents, engine oil, brake fluid, etc. It is known that most stainless steel alloys are quite susceptible to chloride attack.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	More information is needed on the chemical environment seen by LNG fuel tanks and the possible corrosive effect on the tanks.
Explosion -- from mechanical damage to vehicle fuel tank.	While the pressure in LNG fuel tanks is not as high as in CNG tanks, they are still pressure vessels and contain energy in the form of supercooled liquid and gas maintained at pressure. Any tank in the undercarriage of the vehicle is potentially subject to damage from road debris.	The amount of stored energy is the substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	Since the internal pressures are quite similar, the frequency of propane tank failures may serve as a guide here.
Explosion -- from rapid heat transfer to tank.	An explosion of a 9000-gallon liquid hydrogen tank occurred because cooling water applied to the tank after a fire entered, combined with a loss of vacuum in the insulating layer, resulted in rapid heat transfer to the liquid in the tank. The same phenomena is expected to apply to liquefied natural gas tanks.	The force of the explosion tore a 1440-pound bulkhead from the tank which was propelled 250 feet from the original location.	This incident is described in an article entitled "How Safe is the Storage of Liquid Hydrogen."(16)
Explosion -- from trapped LNG.	Trapped LNG which warms produces extremely high pressures if it is confined. Good design includes pressure relief at all points where LNG could be trapped. Good design also prevents moisture from accumulating that could form ice plugs and defeat pressure relief devices.	The amount of stored energy is the substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	The physical principles behind this hazard are well-known. The frequency in vehicle fleet operation is not known.

TABLE 4-2(E). LIQUEFIED NATURAL GAS (LNG) -- HIGH TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Liquified natural gas is not stored or used at high temperatures and does not present a significant high temperature hazard.	--	--

TABLE 4-2(F). LIQUEFIED NATURAL GAS (LNG) – CRYOGENIC TEMPERATURE

Hazard – Event	**Background**	**Consequences**	**Knowledge**
Injury – from skin contact with cold components.	Skin can adhere to cold surfaces and be torn away. Skin contact with LNG can also cause frostbite or cryogenic burns within a few seconds.	Frostbite and personal injury can result.	The flesh-tearing hazard is mentioned in "Safe Handling of Cryogenic Liquids," Compressed Gas Assoc. publication CGA P-12-1993, but no indication is given as to the frequency of occurrence. Some minor cases of LNG fuel-related frostbite have occurred in LNG fleet vehicle operations.
Injury – from skin contact with LNG spills or leaks.	Skin contact with LNG can cause frostbite or cryogenic burns within a few seconds.	Frostbite and personal injury can result.	The flesh-tearing hazard is mentioned in "Safe Handling of Cryogenic Liquids," Compressed Gas Assoc. publication CGA P-12-1993, but no indication is given as to the frequency of occurrence. Some minor cases of frostbite from LNG fuel spills have occurred.
Injury – from eye contact with LNG spills or leaks.	If LNG were to be splashed into the eyes, it would freeze the lens and make it opaque. Eye protection for fuelers and mechanics is important, but not always used.	Eye contact with LNG can cause immediate and permanent blindness.	A search of the literature did not reveal any such injuries to date.
Structural failure – due to contraction	Structural materials will contract substantially when exposed to cryogenic temperatures. If they are not designed for such contraction, permanent deformation or damage may result. If the material is brittle, stress cracking may result.	If the structural member is free to move, there may be no consequence at all. On the other hand, if the member is constrained, large stresses will build up. If the member is also embrittled due to low temperature, then cracking and structural failure of the member may occur. Such failure may endanger the vehicle or vehicle safety components.	The calculation of the degree of contraction with temperature is a textbook problem in engineering. However, if spills and leaks are unanticipated, then the designer may not have made any provision for such an occurrence.

TABLE 4-2(F). LIQUEFIED NATURAL GAS (LNG) -- CRYOGENIC TEMPERATURE (cont.)

Hazard -- Event	Background	Consequences	Knowledge
Structural failure -- due to embrittlement	Many materials, including common steel, become brittle at cryogenic temperatures. Although components that are normally at cryogenic temperatures can be designed for this service, LNG spills can adversely affect the structural integrity of the components that are contacted.	During the time that the materials are cold and brittle, structural failure may occur that may endanger the vehicle or vehicle safety components.	Since the appearance of the material may not change, observers may not realize that the strength has been lost. This effect is the basis for any number of laboratory demonstrations of cryogenic effects and there is a substantial body of knowledge on the effect of temperature material properties. This knowledge should be applied if the designer believes the material may be exposed to LNG.

TABLE 4-2(G). LIQUEFIED NATURAL GAS (LNG) -- MECHANICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Use of liquefied natural gas fuel does not result in significant amounts of stored mechanical energy and hence there is no significant mechanical energy hazards.	–	–

TABLE 4-2(H). LIQUEFIED NATURAL GAS (LNG) -- ELECTRICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Liquefied natural gas fuel does not involve stored electrical energy and does not present a significant electrical hazard.	–	–

TABLE 4-3(A). PROPANE -- FLAMMABILITY

Hazard – Event	**Background**	**Consequences**	**Knowledge**
Fire – from propane dispensing equipment after vehicle collision damage.	While fueling island collisions may be rare, a fire resulting from such a collision could put the fueling facility out of service.	Damage and/or injury from fire, possible disruption of service.	Engineering design for vehicle crash protection is reasonably well-known and can be applied.
Fire – after drive-away during fueling.	Properly designed break-away connectors can prevent most large fuel releases. But these fittings cannot protect against all drive-away scenarios.	Any large fire has the potential to destroy the vehicle and/or injure employees. In addition, a fueling island fire could put the fleet out of commission by preventing fueling.	For typical diesel bus fleets of 200-300 buses, drive-aways occur about once a month.
Fire – from overfilling tanks.	Propane has a much higher volumetric expansion than does water. Therefore, it is necessary to limit the effective capacity of propane fuel tanks to about 80 percent of the water volume. If this is not done, moving the vehicle into a warmer location can result in a release of liquid propane through the tank relief valve.	Often, such tank-venting incidents occur at night after the vehicle has been fueled and then parked indoors. If ignition of the vented propane occurs, the resulting fire can cause considerable property damage.	At least several hundred propane overfilling fires occur each year. For additional information, see Reference (17).
Fire – from static ignition of vented tanks.	During some vehicle maintenance procedures, the vehicle tanks may have to be emptied of fuel. However, effective procedures may not always be used to empty fuel tanks. Allowing a jet of gaseous fuel and fuel droplets to impinge on another object can cause an accumulation of static electricity.	Similar fires while venting natural gas fuel tanks have destroyed the vehicle.	The principles of static electricity are generally well-known, but are not always applied by operators of alternative fuel fleets.
Vehicle fire – from fuel system leaks due to poor design.	While the number of propane-fueled vehicles exceeds that for many other alternative fuels, most propane fuel systems are still designed by aftermarket converters who may not have the vehicle design resources of an OEM automobile manufacturer.	Vehicle fires can result in damage to vehicle, cargo, and occupants.	The design experience base for the use of propane on vehicles is still much smaller than for gasoline or diesel.

TABLE 4-3(A). PROPANE -- FLAMMABILITY (cont.)

Hazard -- Event	Background	Consequences	Knowledge
Vehicle fire -- from fuel system leaks due to improper installation.	Many propane vehicles are converted from other fuels. The experience and skill of those doing such conversions are highly variable.	Vehicle fires can result in damage to vehicle, cargo, and occupants.	The design experience base for the use of propane on vehicles is still much smaller than for gasoline or diesel fuel. Additional information on propane conversion kits is given in Reference (18).
Vehicle fire -- from fuel system leaks due to component failure.	While the number of propane-fueled vehicles exceeds that for many other alternative fuels, propane fuel systems components still do not have the experience base of other fuels.	Vehicle fires can result in damage to vehicle, cargo, and occupants.	The design experience base for the use of propane on vehicles is still much smaller than for gasoline or diesel.
Vehicle Fire -- from other than alternative fuel source.	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts, and eventually involve the vehicle fuel system.	Because of the low boiling point of propane, a BLEVE of the propane fuel tank is possible. More likely is rapid venting of propane gas.	Such vehicle fires do occur and experience with propane in stationary applications indicates that the presence of a propane supply can increase the severity of fire damage by feeding additional fuel to the fire.
Vehicle explosion -- from fuel system leaks	NFPA-58 contains venting provisions to be followed to address this hazard.	When ignited, a confined propane gas-air mixture can produce pressures of up to 800 kPa -- far more than vehicle windows or body structures can withstand.	A number of such explosions have occurred in recreational vehicles where the on-board supply of propane was used for heating and/or cooking.
Building explosion -- from vehicle fuel system leaks	Such leaks can form a flammable zone inside vehicle storage and maintenance buildings and, if ignited, can cause building explosions and serious injuries.	When ignited, a confined propane gas-air mixture can produce pressures of up to 800 kPa -- far more than building structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	The National Electric contains provisions for use of explosion-proof electrical devices in the lower levels of buildings where propane is used.

TABLE 4-3(B). PROPANE -- CORROSIVITY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Propane fuel is not corrosive and does not present a significant corrosivity hazard.	–	–

TABLE 4-3(C). PROPANE -- TOXICITY

Hazard – Event	Background	Consequences	Knowledge
Asphyxiation – from displacement of air.	Propane gas is heavier than air and can collect in low areas and in unventilated spaces, such as maintenance pits.	If a person does not receive fresh air soon, serious injury can occur.	The causes and effects of asphyxiation are discussed in standard safety texts.(19)
Health effects – from fuel toxicity.	OSHA has set a time-weighted average (TWA) of 1000 ppm as the personal exposure limit for propane vapor. Other authorities, such as the American Conference of Governmental Industrial Hygienists (ACGIH) do not support the view that propane is toxic and list it as a simple asphyxiant. Conversations with NIOSH did not reveal the rational for a more stringent classification.	Probably none, since the more stringent toxicity concern seems to be without basis.	The basis for this OSHA personal exposure limit may be vague, but it's currently the law.

TABLE 4-3(D). PROPANE -- HIGH PRESSURE

Hazard -- Event	Background	Consequences	Knowledge
Explosion -- from corrosion of fuel tank.	While the pressure in propane fuel tanks is not as high as in CNG tanks, they are still pressure vessels and contain energy in the form of liquefied gas maintained at pressure.	Any pressure vessel explosion is potentially serious.	An approximate failure rate for pressure vessels of all types is about one failure per year per 10,000 vessels in service.(29) Not all such failures are catastrophic.
Explosion -- from mechanical damage to fuel tank.	While the pressure in propane fuel tanks is not as high as in CNG tanks, they are still pressure vessels and contain energy in the form of liquefied gas maintained at pressure. If the propane fuel tank is mounted in the vehicle undercarriage, then it is susceptible to failure from mechanical damage from road debris, etc.	Any pressure vessel explosion is potentially serious.	See above.

TABLE 4-3(E). PROPANE -- HIGH TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Propane is not stored or used at high temperatures and does not present a significant high temperature hazard.	--	--

TABLE 4-3(F). PROPANE -- CRYOGENIC TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
Injury – from contact with cold components.	Release of propane produces vigorous cooling due to evaporation of liquid propane and subsequent expansion of the gas. Unlike cryogenic fuels which feature low temperatures, the low temperatures from propane releases can be unexpected.	Personal injury due to frostbite can occur.	Release of propane can produce temperatures of -40°C or less.

TABLE 4-3(G). PROPANE -- MECHANICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Use of propane fuel does not result in significant amounts of stored mechanical energy and hence there is no significant mechanical energy hazards.	–	–

TABLE 4-3(H). PROPANE -- ELECTRICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	The use of propane fuel does not involve stored electrical energy and does not present a significant electrical hazard.	–	–

TABLE 4-4(A). METHANOL – FLAMMABILITY

Hazard – Event	Background	Consequences	Knowledge
Fire – from fuel dispensing equipment after vehicle collision damage.	The danger of methanol fueling island collisions is similar to that from gasoline fueling islands.	Such a collision could result in a fire.	Design for crash protection is reasonably well-known and can be applied.
Vehicle fire – from fuel system leaks due to poor design.	Although methanol fuel systems are nearly the same as those generally used on motor vehicles, there can be challenges in the selection of compatible materials.	Any fuel system fire can damage or consume the vehicle.	The US EPA has compared the vehicle fire rate as a function of Reid vapor pressure (RVP) of the fuel and found that as the fuel vapor pressure decreases, there are fewer vehicle fires.(23) Methanol has a lower RVP than gasoline.
Vehicle fire – from fuel system leaks due to component failure.	The use of methanol requires some changes in fuel system materials and components.	Any fuel system fire can damage or consume the vehicle.	The US EPA has compared the vehicle fire rate as a function of Reid vapor pressure of the fuel and found that as the fuel vapor pressure decreases, there are fewer vehicle fires.(23) Methanol has a lower RVP than gasoline.
Vehicle Fire – from other than alternative fuel source.	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts, and eventually involve the vehicle fuel system.	The consequences of such a fire will be very like that of a gasoline fire of similar origin.	The overall fire rate for medium and heavy duty trucks is about 6 fires per 100 million miles of operation.(23) Most such fires originate in the electrical system.
Fire – after drive-away during fueling.	Properly designed break-away connectors can prevent most such fuel releases.	Although unlikely, a fueling island fire could put the fleet out of commission by preventing fueling.	At retail gasoline stations, one oil company study found one service station fire due to a drive-away per 75 million fuelings. Since the vapor pressure of methanol is lower, the fire rate would be expected to be somewhat lower.

TABLE 4-4(B). METHANOL – CORROSIVITY

Hazard – Event	Background	Consequences	Knowledge
Corrosion – to metal components.	Being a polar liquid, methanol is slightly acidic. Thus, it can corrode electropositive metals such as aluminum and zinc. Therefore, materials traditionally used with hydrocarbon fuels may not be satisfactory in contact with methanol. The large M-85 vehicle program instigated by the California Energy Commission has produced a wealth of information concerning proper materials selection for methanol fuel. Efforts by Ford and General Motors have also led to materials specifications.	Such corrosion can fuel leaks if fuel system components are not made of methanol-compatible materials.	Information contained in Perry's Chemical Engineers' Handbook covers the basic materials data for methanol.(24) The Canadian Oxygenated Fuels Association has produced a guide to methanol fueling system design.(25) Additional materials compatibility information may require laboratory testing.
Seal failures – deterioration of gaskets and seals	While methanol is not very corrosive per se, it can have deleterious effects on gaskets, o-rings, and other seals which were optimized for other fuels, such as gasoline or diesel.	Seal failures usually result in fuel leaks. Such leaks can lead to fire, injury, and explosion hazards.	See above note for corrosion.

TABLE 4-4(C). METHANOL -- TOXICITY

Hazard -- Event	Background	Consequences	Knowledge
Adverse health effects -- from exposure to fuel vapors.	Methanol vapors are toxic and excessive exposure to methanol vapors can cause adverse health effects, including blindness.	In humans and other primates, methanol is a neurotoxin and excessive exposure can cause blindness and death. In non-primates, methanol is metabolized. Therefore, methanol is considered biodegradable in the environment.	General information on methanol health effects is given in Reference (26). NIOSH studied exposure of bus fuelers and mechanics to methanol at SCRTD and found the methanol vapor exposure to be negligible compared to accepted health standards.
Adverse health effects -- from skin contact with fuel .	Excessive skin contact with methanol can cause adverse health effects, including blindness. The use of gloves and other personal protective gear is recommended as well as procedures to minimize skin contact with fuel.	In humans and other primates, methanol is a neurotoxin and excessive exposure can cause blindness and death.	NIOSH studied the exposure of bus mechanics to methanol at SCRTD and found the exposure to be generally acceptable if good work practices were used for breaking into the fuel system. Complete information on selection of proper protective gear is given in Reference (27).

TABLE 4-4(D). METHANOL -- HIGH PRESSURE

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Methanol is not stored or used at high pressures and does not present a significant high pressure hazard.	–	–

TABLE 4-4(E). METHANOL – HIGH TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Methanol is not stored or used at high temperatures and does not present a significant high temperature hazard.	–	–

TABLE 4(F). METHANOL -- CRYOGENIC TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Methanol is not stored or used at cryogenic temperatures and does not present a significant cryogenic temperature hazard.	–	–

TABLE 4-4(G). METHANOL – MECHANICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	The use of methanol fuel does not involve equipment with significant amounts of stored mechanical energy and hence does not present a significant mechanical energy hazard.	–	–

TABLE 4(H). METHANOL – ELECTRICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	The use of methanol fuel does not involve stored electrical energy and does not present a significant electrical hazard.	–	–

TABLE 4-5(A). ETHANOL -- FLAMMABILITY

Hazard – Event	**Background**	**Consequences**	**Knowledge**
Fire – from fuel dispensing equipment after vehicle collision damage.	The danger of ethanol fueling island collisions is similar to that from gasoline fueling islands.	Such a collision could result in a fire.	Design for crash protection is reasonably well-known and can be applied.
Vehicle fire – from fuel system leaks due to poor design.	Although ethanol fuel systems are nearly the same as those generally used on motor vehicles, there can be challenges in the selection of compatible materials.	Any fuel system fire can damage or consume the vehicle.	The US EPA has compared the vehicle fire rate as a function of Reid vapor pressure of the fuel and found that as the fuel vapor pressure decreases, there are fewer vehicle fires. (29) Ethanol has a lower RVP than gasoline.
Vehicle fire – from fuel system leaks due to component failure.	The use of ethanol requires some changes in fuel system materials and components.	Any fuel system fire can damage or consume the vehicle.	The US EPA has compared the vehicle fire rate as a function of Reid vapor pressure of the fuel and found that as the fuel vapor pressure decreases, there are fewer vehicle fires. (29) Ethanol has a lower RVP than gasoline.
Vehicle Fire – from other than alternative fuel source	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts, and eventually involve the vehicle fuel system.	The consequences of such a fire will be very like that of a gasoline fire of similar origin.	The overall fire rate for medium and heavy duty trucks is about 6 fires per 100 million miles of operation. (30) Most such fires originate in the electrical system.
Fire – after drive away during fueling	Properly designed break away connectors can prevent most such fuel releases.	Although unlikely, a fueling island fire could put the fleet out of commission by preventing fueling.	At retail gasoline stations, one oil company study found one service station fire due to a drive-away per 75 million fuelings. Since the vapor pressure of ethanol is lower than gasoline, the fire rate would be expected to be somewhat lower.

TABLE 4-5(B). ETHANOL -- CORROSIVITY

Hazard -- Event	Background	Consequences	Knowledge
Corrosion -- to metal components.	Being a polar liquid, ethanol is slightly acidic. Thus, it can corrode electropositive metals such as aluminum and zinc.	Such corrosion can fuel leaks if fuel system components are not made of ethanol-compatible materials.	Information contained in Perry's Chemical Engineers' Handbook covers the basic materials data for ethanol.[31] The large M-85 vehicle program instigated by the California Energy Commission has produced a wealth of information concerning proper materials selection for methanol fuel. Efforts by Ford and General Motors have also led to materials specifications for methanol. It is likely that most of this experience will transfer over to ethanol fuel, given the chemical similarity of methanol and ethanol. Additional materials compatibility information may require laboratory testing.
Seal failures -- deterioration of gaskets and seals.	While ethanol is not very corrosive per se, it can have deleterious effects on gaskets, o-rings, and other seals which were optimized for other fuels, such as gasoline or diesel.	Seal failures usually result in fuel leaks. Such leaks can lead to fire, injury, and explosion hazards.	See above note for corrosion.

TABLE 4-5(C). ETHANOL -- TOXICITY

Hazard – Event	**Background**	**Consequences**	**Knowledge**
Adverse health effects – from exposure to fuel vapors.	Ethanol vapors are toxic and excessive exposure to methanol vapors can cause adverse health effects. The TLV for ethanol is 1000 ppm. (The odor threshold is about 5 ppm.)	Ethanol toxicity can cause long-term health effects as well as intoxication due to acute vapor exposures.	NIOSH studied exposure of bus fuelers to methanol at SCRTD and found the exposure to be negligible compared to accepted health standards. By extension, the exposure to ethanol, which has a higher TLV and lower volatility than methanol is also likely to be negligible.
Adverse health effects – from ingestion of fuel.	Normally, there would be little temptation to ingest fuel. However, ethanol fuel is widely advertised as being grain-based. And not all people may understand that the denaturing process involves the addition of toxic substances to the ethanol, and a point not often made in the marketing of this fuel.	The health consequences depend on the denaturant used.	Data from the American Association of Poison Control Centers indicates that about 30,000 people are treated for alcohol poisoning or overdose each year.
Adverse health effects – from skin contact with fuel.	While ethanol is not especially toxic via dermal exposure, excessive skin contact with any fuel should be avoided. The use of gloves and other personal protective gear is recommended to minimize skin contact with fuel.	Contact with ethanol can cause skin drying and irritation.	Due to the long history of the use of ethanol as a solvent, the health effects of pure ethanol are well-documented. See for example Patty's Industrial Hygiene. (29)

TABLE 4-5(D). ETHANOL – HIGH PRESSURE

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Ethanol fuel is not stored or used at high pressures and does not present a significant high pressure hazard.	–	–

TABLE 4-5(E). ETHANOL – HIGH TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Ethanol fuel is not stored or used at high temperatures and does not present a significant high temperature hazard.	–	–

TABLE 4-5(F). ETHANOL – CRYOGENIC TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
None – no significant hazards identified.	Ethanol fuel is not stored or used at cryogenic temperatures and does not present a cryogenic temperature hazard.	–	–

TABLE 5(G). ETHANOL -- MECHANICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of ethanol fuel does not involve stored mechanical energy and hence does not present significant mechanical energy hazards.	--	--

TABLE 5(H). ETHANOL -- ELECTRICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of ethanol fuel does not involve stored electrical energy and does not present a significant electrical hazard.	--	--

TABLE 4-6(A). BIODIESEL -- FLAMMABILITY

Hazard – Event	Background	Consequences	Knowledge
Fire – from fuel dispensing equipment after vehicle collision damage.	The danger of biodiesel fueling island collisions is similar to that from conventional diesel fueling islands.	Such a collision could result in a fire.	Design for crash protection is reasonably well-known and can be applied.
Vehicle fire – from fuel system leaks due to poor design.	Although biodiesel fuel systems are nearly the same as those generally used on motor vehicles, there can be challenges in the selection of compatible materials.	Fires from low-volatility liquid fuels tend to be limited by the relatively slow evaporation of the fuel. Still, any fuel system fire can damage or consume the vehicle.	Because the flammability of biodiesel fuel is similar to that of diesel fuel, the wide experience with conventional diesel fuels is applicable here.
Vehicle fire – from fuel system leaks due to component failure.	The use of biodiesel requires some changes in fuel system materials and components.	Fires from low-volatility liquid fuels tend to be limited by the relatively slow evaporation of the fuel. Still, any fuel system fire can damage or consume the vehicle.	Because the flammability of biodiesel fuel is similar to that of diesel fuel, the wide experience with conventional diesel fuels is applicable here.
Vehicle Fire -- from other than alternative fuel source.	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts, and eventually involve the vehicle fuel system.	The severity of such fires is expected to be similar to that of fires that involve a diesel fuel system.	Because the flammability of biodiesel fuel is similar to that of diesel fuel, the wide experience with conventional diesel fuels is applicable here.
Fire -- after drive-away during fueling.	Properly designed break-away connectors can prevent most such fuel releases. Moreover, like diesel fuel, biodiesel fuel is below its flash point at ambient temperatures. Therefore, an immediate fire from spilled fuel is most unlikely.	Although unlikely, a fueling island fire could put the fleet out of commission by preventing fueling.	Because the flammability of biodiesel fuel is similar to that of diesel fuel, the wide experience with conventional diesel fuels is applicable here.

TABLE 4-6(B). BIODIESEL – CORROSIVITY

Hazard – Event	Background	Consequences	Knowledge
Seal Failures – deterioration of gaskets and seals.	Biodiesel fuel can attack gaskets and seals that would work well with conventional diesel fuels.	While such failures may merely result in impaired operation of the vehicle, seal failures that result in fuel leaks can result in vehicle fires.	Early results with biodiesel fuel demonstration fleets have shown that seal problems do occur. It is not known how easily materials may be found which are acceptable.

TABLE 4-6(C). BIODIESEL – TOXICITY

Note: Since most biodiesel fuel is used as part of a mixture with diesel fuel, the toxicity properties of biodiesel fuel mixtures are usually determined by the diesel fuel component.

Hazard – Event	Background	Consequences	Knowledge
Adverse Health Effects – from skin contact with fuel.	While biodiesel fuel is not expected to be especially toxic via dermal exposure, excessive skin contact with any fuel should be avoided. The use of gloves and other personal protective gear is recommended to minimize skin contact with fuel.	The human health effects of biodiesel are not as yet well-defined. Health effects of the methanol component include possible visual impairment and serious injury for severe exposures.	There is little information on the toxicity of biodiesel fuel, particularly considering that methanol toxicity primarily affects humans and primates.
Adverse Health Effects – from ingestion of fuel.	While ingestion of fuel would not normally be considered a hazard, there is marketing information that stresses the food crop origins of biodiesel fuel. However, biodiesel fuel is not just vegetable oil, it has been reacted with methanol. If ingested it will be broken down by the body into vegetable oil and methanol, which has toxic effects.	The human health effects of biodiesel are not as yet well-defined. Health effects of the methanol component include possible visual impairment and serious injury for severe exposures.	There is little information on the toxicity of biodiesel fuel, particularly considering that methanol toxicity primarily affects humans and primates.

TABLE 4-6(D). BIODIESEL -- HIGH PRESSURE

Hazard – Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Biodiesel fuel is not used at high pressure and does not present a significant high-pressure hazard.	–	–

TABLE 4-6(E). BIODIESEL -- HIGH TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Biodiesel fuel is not stored at high temperatures and does not present a significant high temperature hazard.	–	–

TABLE 4-6(F). BIODIESEL -- CRYOGENIC TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Biodiesel fuel is not stored at cryogenic temperatures and does not present a significant cryogenic hazard.	–	–

TABLE 4-6(G). BIODIESEL -- MECHANICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of biodiesel fuel does not involve a significant amount of stored mechanical energy.	–	–

TABLE 4-6(H). BIODIESEL -- ELECTRICAL ENERGY

Hazard – Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of biodiesel fuel does not involve stored electrical energy and does not present a significant electrical hazard.	–	–

TABLE 4-7(A). HYDROGEN – FLAMMABILITY

Hazard – Event	Background	Consequences	Knowledge
Fire – from leaking underground piping to fueling island after corrosion.	Piping from the compressor to the dispenser has pressures of 3000-4000 psig. Although such piping is often made of stainless steel, which resists many types of corrosion, some types of stainless steel are very susceptible to chloride corrosion.	The high line pressure means that large amounts of fuel can be released quickly.	The oil refining industry has considerable experience with hydrogen at high pressures. Work and reports of the American Petroleum Institute (API) should be consulted for information.
Fire – from gas dispensing equipment after vehicle collision damage.	Piping from the hydrogen supply to the dispenser may have pressures of 3000-4000 psig. While fueling island collisions may be rare, there is the potential to release large amounts of fuel.	The high line pressure means that large amounts of fuel can be released quickly.	Design for crash protection is reasonably well-known and can be applied.
Vehicle fire – from fuel system leaks due to poor design.	The use of compressed gases involves materials, components, and techniques which have not been generally used on motor vehicles.	Fires from liquid fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels this limitation does not exist and large fires can develop quickly.	The design experience base for use of high pressure gaseous fuels on vehicles is still relatively small. This is especially true for hydrogen-fueled vehicles.
Vehicle fire – from fuel system leaks due to improper installation.	Many hydrogen-fueled vehicles are apt to be converted from other fuels. The experience and skill of those doing such conversions is highly variable.	Fires from liquid fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels this limitation does not exist and large fires can develop quickly.	The experience base for installations using high pressure gaseous fuels on vehicles is still relatively small. This is especially true for hydrogen-fueled vehicles.
Vehicle fire – from fuel system leaks due to component failure.	The use of hydrogen gas involves materials and components which have not been generally used on motor vehicles.	Fires from liquid fuels are limited by the relatively slow evaporation of the fuel. For gaseous fuels this limitation does not exist and large fires can develop quickly.	The experience base for components for high pressure gaseous fuels on vehicles is still relatively small. This is especially true for hydrogen-fueled vehicles.
Vehicle Fire – from other than alternative fuel source.	Fleet experience shows that many vehicle fires are of electrical origin. These fires then involve other vehicle components, such as plastic parts, and eventually involve the vehicle fuel system.	A gaseous fuel under high pressure has the potential to significantly increase the size and intensity of a vehicle fire.	Vehicle fires do occur. However, we are not aware of any experience with vehicle fires that involved hydrogen.

TABLE 4-7(A). HYDROGEN -- FLAMMABILITY (cont.)

Hazard – Event	Background	Consequences	Knowledge
Fire – after drive-away during fueling.	Properly designed break-away connectors can prevent most large fuel releases. But these fittings cannot protect against all drive-away scenarios. Static electricity may ignite such fuel releases. The ignition energy for hydrogen is lower than for other fuels.	Any large fire has the potential to destroy the vehicle and/or injure employees. In addition, a fueling island fire could put the fleet out of commission by preventing fueling.	The type and configuration of hydrogen fueling dispensers remains to be determined. The hazard depends on the configuration of the fueling dispenser.
Fire – from static ignition of vented tanks.	Several such fires have already occurred as CNG tanks were vented to the atmosphere. If hydrogen tanks are vented, a similar possibility exists. Hydrogen has an especially low threshold for static ignition, compared to hydrocarbon fuels.	Some of these natural gas fires have destroyed vehicles, a hydrogen fire would be expected to be similarly damaging.	The properties of static electricity are generally well-known, but are not always applied by operators of alternative fuel fleets.
Vehicle explosion – from fuel system leaks.	A vehicle explosion from leaking methane has occurred in a transit bus at Houston Metro. Like LNG vapor, hydrogen does not have an odor to warn of leaks and such an explosion with hydrogen is also possible.	When ignited, a confined hydrogen gas-air mixture can produce pressures of up to 800 kPa -- far more than vehicle glass or body structures can withstand.	One flammable gas explosion of methane has occurred in an articulated transit bus under repair at Houston Metro. An analysis of fuel gas leakage into the interior of a vehicle is given in Reference(33).
Building explosion -- from vehicle fuel system leaks.	Such leaks can form a flammable zone inside vehicle storage and maintenance buildings and if ignited can cause building explosions and serious injuries. Experience to date with compressed natural gas suggests that fuel system leaks will be relatively frequent until the technology for high pressure gaseous fuel use on vehicles becomes more mature.	When ignited, a confined hydrogen gas-air mixture can produce pressures of up to 800 kPa -- far more than vehicle structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	Though some fluid dynamic modeling of leaks from high pressure gaseous fuel systems has been done for the FTA, there is a lack of experimental data on flammable plume behavior and also a lack of codes and standards to guide the design of buildings for this fuel.
Building explosion – from vehicle PRD failure.	Such leaks can form a large flammable zone inside vehicle storage and maintenance buildings and if ignited can cause building explosions and serious injuries. Experience to date suggests that PRD failures will be relatively frequent until the technology for use on vehicles becomes more mature.	When ignited, a confined hydrogen gas-air mixture can produce pressures of up to 800 kPa -- far more than building structures can withstand. For example, overpressures greater than 7 - 15 kPa will cause a brick wall to fail.	Though some fluid dynamic modeling of leaks from high pressure gaseous fuel systems has been done for the FTA, there is a lack of experimental data on flammable plume behavior and also a lack of codes and standards to guide the design of buildings for this fuel.

TABLE 4-7(B). HYDROGEN -- CORROSIVITY

Hazard – Event	Background	Consequences	Knowledge
Embrittlement of Metals -- from exposure to hydrogen.	Hydrogen can cause embrittlement of metal alloys. This can cause catastrophic failure of pressure vessels containing hydrogen fuel.	The failure of a component containing hydrogen gas at high pressure can result in a loss of fuel and a fire and/or a pressure vessel failure with consequent damage or injury.	Hydrogen embrittlement has been extensively studied in other industries. However, technology transfer to transit may be poor.

TABLE 4-7(C). HYDROGEN -- TOXICITY

Hazard – Event	Background	Consequences	Knowledge
Asphyxiation -- from displacement of air.	Although hydrogen it non-toxic, it is lighter than air and can collect in enclosed spaces which are not vented at the top. If enough air is displaced, asphyxiation may occur.	If a person does not receive fresh air quickly, serious injury can occur.	The medical effects of asphyxiation are described in standard occupational health references.

TABLE 4-7(D). HYDROGEN -- HIGH PRESSURE

Hazard -- Event	Background	Consequences	Knowledge
Explosion -- of vehicle fuel tank.	Even though CNG fuel tanks must meet rigorous standards, several fuel tanks have failed due to unforeseen environmental conditions. Thus, it is likely that the same hazard will apply to tanks with pressurized hydrogen.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	If hydrogen is stored on-board in fuel tanks that are similar to those used for compressed natural gas, then engineering information for CNG will apply.
Missile damage -- from flying about of parts during disassembly.	Compressed hydrogen fuel systems are under high pressure. Improper disassembly procedures or faulty pressure indications can cause parts to act as projectiles.	Although the projectiles may not be large or heavy, the close proximity of people increases the risk.	Several such incidents have occured in CNG fleets and fleets using high pressure hydrogen may also expect them too.
Missile damage -- from pressure gage failure.	Pressure gages are known to fail under pressure. While the hazard is largely controlled in stationary applications, the vehicle environment can be more severe.	Although the projectiles may not be large or heavy, the close proximity of people increases the risk.	Gage manufacturers generally include features to insure that any failure does not occur on the front of the gage. However, proper installation of the gage is necessary for those features to be effective. No such incident involving a hydrogen vehicle is known to date.
Flailing damage -- from fueling hose failure.	Compressed hydrogen fueling hoses will carry gas at high pressure. A broken hose will flail wildly if unrestrained. Excess flow devices may help, but due to the high fill rates required for fleet operations, the allowable flow rate must be relatively large.	Although the fueling hose may not be especially heavy, the necessary close proximity of people greatly increases the risk.	The configuration of hydrogen fueling dispensers remains uncertain. However, for high pressure hydrogen gas, the hazard is likely to be similar to that for CNG.
Explosion -- from corrosion of fuel tank.	Compressed hydrogen fuel tanks will contain a lot of energy in the form of a large volume of gas maintained at high pressure. If less than chemically pure hydrogen is used as a fuel, corrosion from impurities may occur.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	No incidents with hydrogen vehicle tanks are known.
Explosion -- from mechanical damage to fuel tank.	Compressed hydrogen fuel tanks contain a lot of energy in the form of a large volume of gas maintained at high pressure.	The amount of stored energy is substantial and the rate of energy release is high. Any pressure vessel explosion is potentially serious.	Experience with CNG tanks shows that mechanical damage of vehicle fuel tanks is possible if the tanks are exposed to road hazards.

TABLE 4-7(E). HYDROGEN -- HIGH TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Hydrogen is not stored at high temperatures and does not present a significant high temperature hazard.	--	--

TABLE 4-7(F). HYDROGEN -- CRYOGENIC TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	This analysis assumes that the hydrogen is stored as a compressed gas. If it is stored in cryogenic form, then the hazard events listed for liquefied natural gas will apply.	--	--

TABLE 4-7(G). HYDROGEN -- MECHANICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of hydrogen does not involve a significant amount of stored mechanical energy.	--	--

TABLE 4-7(H). HYDROGEN -- ELECTRICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	Hydrogen fuel does not involve stored electrical energy and does not present a significant electrical hazard.	–	–

TABLE 4-8(A). ELECTRICITY -- FLAMMABILITY

Hazard -- Event	Background	Consequences	Knowledge
Fire -- due to electrical short or overload.	Currently, most fires on heavy duty fleet vehicles originate as electrical fires. Electric vehicles will have a much greater power capability and hence a greater potential hazard.	A fire can result in damage to or loss of the vehicle as well as injury to the occupants.	Recently (June 1994) two Ford Ecostar electric vehicles experienced electrical fires during battery charging.
Fire -- due to electrical component failure.	Currently, most fires on heavy duty fleet vehicles originate as electrical fires. Electric vehicles will have a much greater power capability and hence a greater potential hazard.	A fire can result in damage to or loss of the vehicle as well as injury to the occupants.	Several experimental electric vehicles have suffered electrical fires, including most recently the Ford Ecostar.
Fire -- due to contact with hot electrolyte.	Some battery systems use very hot electrolytes. Since the autoignition temperature of hydrocarbons can be as low as 220°C, contact with heat from the battery could lead to a vehicle fire.	A fire can result in damage to or loss of the vehicle as well as injury to the occupants.	Both the electrolyte temperature and the ignition temperatures of other materials are reasonably well-known. The major uncertainty is the ability to isolate the high temperature in all types of normal operation and during traffic accidents.

TABLE 4-8(B). ELECTRICITY -- CORROSIVITY

Hazard – Event	Background	Consequences	Knowledge
Corrosion – from battery electrolyte.	Most battery systems proposed for electric vehicles have electrolytes which are corrosive. Leakage of this electrolyte can cause damage to and/or failure of other vehicle components. A recent example from a non-electric vehicle is the failure of CNG fuel tanks from spilled electrolyte from batteries carried to start other vehicles.	The consequences can be either minor or major depending on the vehicle component affected and the importance of that component to maintaining safe operation of the vehicle.	Little data are available on the degree to which this will be a problem in actual electric vehicles.
Corrosion – from electrolysis.	Leakage current may cause electrolysis of metal vehicle components. While such electrolysis could take place with current battery-powered accessory circuits, the larger currents and higher voltages used for electric propulsion could increase the danger of electrolytic corrosion.	The consequences can be either minor or major depending on the vehicle component affected and the importance of that component to maintaining safe operation of the vehicle.	Little data are available on the degree to which this will be a problem in actual electric vehicles.

TABLE 4-8(C). ELECTRICITY -- TOXICITY

Hazard -- Event	Background	Consequences	Knowledge
Health hazard -- from contact with battery electrolyte.	Many candidate battery electrolytes are corrosive and toxic. They are potential hazardous via skin contact or inhalation of fumes or vapors.	The toxic consequences depends on the composition of the electrolyte.	The degree of knowledge depends on the material composition(s) involved.

TABLE 4-8(D). ELECTRICITY -- HIGH PRESSURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of electricity does not involve high pressures and hence there is not a significant high pressure hazard associated with the use of electricity.	--	--

TABLE 4-8(E). ELECTRICITY -- HIGH TEMPERATURE

Hazard – Event	Background	Consequences	Knowledge
Burns – from contact with battery.	Some proposed battery systems operate at high temperatures. Contact with such temperatures could occur during vehicle repair and cause unexpected burns.	Any burn is a potentially serious injury.	The degree of hazard depends on the type of battery system used and on the design configuration of the vehicle.
Burns – from contact with leaking battery electrolyte after component failure.	Some proposed battery systems operate at high temperatures. Contact with such temperatures could cause burns.	Any burn is a potentially serious injury.	The degree of hazard depends on the type of battery system used and on the design configuration of the vehicle.
Burns – from contact with leaking battery electrolyte after traffic accident.	Some proposed battery systems operate at high temperatures. A damaged battery pack could leak electrolyte at high temperature. Contact with such temperatures could cause burns.	Any burn is a potentially serious injury.	The degree of hazard depends on the type of battery system used and on the design configuration of the vehicle.

TABLE 4-8(F). ELECTRICITY -- CRYOGENIC TEMPERATURE

Hazard -- Event	Background	Consequences	Knowledge
None -- no significant hazards identified.	The use of electricity does not involve cryogenic temperatures and hence there is not a significant cryogenic temperature hazard.	--	--

TABLE 4-8(G). ELECTRICITY -- MECHANICAL ENERGY

Hazard -- Event	Background	Consequences	Knowledge
Lifting-falling hazard -- from changing battery packs.	Electric vehicle battery packs are not expected to last the life of the vehicle and will need to be replaced. Such battery packs are heavy components and will require special handling.	Given the weight of battery packs, a falling battery pack could cause serious trauma.	Although engines and transmissions are heavy components which are routinely replaced, experience with such techniques may not provide much information on battery packs which are several times as heavy and which require different handling techniques.

TABLE 4-8(H). ELECTRICITY – ELECTRICAL ENERGY

Hazard– Event	**Background**	**Consequences**	**Knowledge**
Shock hazard – from battery charger connection.	Electric vehicles are likely to employ much higher voltages than used for vehicle accessory circuits, as many as several hundred volts. Battery charger connections are subject to severe handling and abuse. Connections may need to be made to vehicles which are wet with road salt or during heavy rains.	Major electric shocks can cause death or injury. Even minor electric shocks can cause injury by causing involuntary movement.	The hazards associated with electric shock are well-known, but there is relatively little experience with the hazard from electric vehicles in everyday use.
Shock hazard -- from on-board electric supply during vehicle repair.	Electric vehicles are likely to employ much higher voltages than used for vehicle accessory circuits, as many as several hundred volts. Mechanics and others who repair vehicles will need to follow strict procedures to avoid electric shocks.	Major electric shocks can cause death or injury. Even minor electric shocks can cause injury by causing involuntary movement.	The hazards associated with electric shock are well-known: voltages less than 24 volts are not considered to present a shock hazard, while voltages greater than 50 volts are considered potentially lethal.(24) There is relatively little experience with the hazard from electric vehicles in everyday use.
Shock hazard -- from on-board electric supply due to component failure.	Electric vehicles are likely to employ much higher voltages than used for vehicle accessory circuits, as many as several hundred volts. A component failure could expose the occupants to these voltages.	Major electric shocks can cause death or injury. Even minor electric shocks can cause injury by causing involuntary movement.	The hazards associated with electric shock are well-known, but there is relatively little experience with the hazard from electric vehicles in everyday use.
Shock hazard – from on-board electric supply after traffic accident.	Electric vehicles are likely to employ much higher voltages than used for vehicle accessory circuits, as many as several hundred volts. A damaged electrical system component could expose the occupants to these voltages.	Major electric shocks can cause death or injury. Even minor electric shocks can cause injury by causing involuntary movement.	The hazards associated with electric shock are well-known, but there is relatively little experience with the hazard from electric vehicles in everyday use.

TABLE 4-8(H). ELECTRICITY -- ELECTRICAL ENERGY (cont.)

Hazard– Event	Background	Consequences	Knowledge
Electromagnetic field damage – from electric traction equipment.	Cargo carried on-board vehicles commonly includes magnetic data processing media as well as a variety of electronic devices which may be subject to interference from electromagnetic fields arising from electric traction equipment. Because of the relatively large power involved in electric traction as well as the complex waveforms generated by traction control modules, such interference may be much more severe than from traditional vehicle electrical systems.	Damage to electronic media or interference with the operation of electronic devices.	While the principles of EMI control are well-known, it is difficult to predict whether a given device in a real-world situation will be affected by EMI.
Electric and magnetic field health effects – from electric traction equipment.	Several types of health effects have been imputed to human exposure to electric and/or magnetic fields. The main concern is possible elevated rates of cancer, though various other physiological changes are also suspected to be caused by electric and/or magnetic fields.	The suggested health effects of exposure to electromagnetic radiation are serious, especially cancers, such as leukemia. However, the cause and effect and dose response relationships are far from proven.	Much additional information is needed confirm or deny the various hypotheses on health effects of electromagnetic fields. The physical principles involved are well-described in Reference(35). A summary of the issues is given in Reference(36). Current epidemiologic results are reviewed in Reference(37). A report on the most recent results is given in Reference(38).

4.5 ALTERNATIVE FUEL SAFETY CASE STUDIES

While the summary list of hazards provides a systematic approach to alternative fuel hazards, that summary list does not allow highlighting of the case histories of safety incidents that have actually occurred. Therefore, the case histories below are presented.

4.5.1 Methanol Vehicle Fire

A medium-duty local delivery truck running on M-85 fuel experienced a fuel system leak and fire. The situation was first noticed while the truck was on the freeway and the driver noticed the check engine light on. Upon pulling over, the driver saw flames coming from the engine compartment. He tried to extinguish the fire with a hand extinguisher, but was not successful. The local fire department was called and extinguished the fire.

A methanol fuel leak had occurred in the vicinity of the cold start injector. The leaking fuel ignited, probably on the exhaust manifold, and caused a fire in the front end of the truck. Although no cargo was damaged or destroyed, the engine compartment was extensively damaged and the vehicle was a total loss. Ironically, the incident occurred in Southern California where cold-start injectors are not needed for vehicle operation.

4.5.2 LNG Bus Explosion

A methane explosion occurred inside an LNG-powered transit vehicle on December 6, 1992. The vehicle, a 60-ft. articulated bus had just been delivered and was being readied for operation on LNG. The manufacturer's representative was repairing a natural gas fuel system leak when a combustible gas detector located on-board the vehicle sounded an alarm. Although such repairs were supposed to be performed outdoors, the weather was inclement and the work was being done in a normal bus repair bay. After becoming aware of the leak, the mechanic used a switch to override this alarm to start the bus to move it outside. However, when the bus was started, a relay in the air conditioning system ignited a flammable methane- air mixture that had accumulated in the interior of the bus. The resulting explosion blew out all of the windows on the bus as well as the roof hatches and the bellows.

4.5.3 High Pressure CNG Fittings As Projectiles

A large transit property with CNG buses reported that on several occasions, experienced mechanics had loosened CNG fuel line fittings with as much as 60 psig 0pressure on the system. The pressure gages on the vehicles were faulty and often indicated zero even with this much pressure. Thus, mechanics thought the system was at zero pressure even though it was not. The result was fittings flying across the shop.

4.5.4 Propane Tank Damage

A recreational vehicle was fitted with a propane tank underneath the vehicle's floor. Sometime later the owner noticed that water had accumulated on the floor inside the vehicle. To clean out the drain hole in the floor, the vehicle owner got a drill and drilled out the drain holes. In doing so he drilled into the propane tank. A large propane leak ensued, but there was no fire.

4.5.5 Pressure Relief Device (PRD) Failure on CNG Bus

Several transit properties using CNG have experienced PRD failures. Large fleets of CNG buses have experienced multiple such failures. These failures have resulted in the release of one or more full tanks of CNG into the bus fueling area. One such failure occurred when a recently fueled CNG bus with roof-mounted tanks was taken into the garage for light maintenance. A PRD failure occurred and the gas-fired infrared heaters in use in the shop ignited the escaping gas. Damage from fire and water used to fight the fire was fairly extensive.

4.5.6 CNG Cascade Relief Valve Failure

At midnight, a night shift mechanic for a fleet of medium-duty CNG vehicles noticed a strong odor of natural gas in the parking lot. He traced it to the cascade and found a relief valve stuck open on the top tank. He closed the valve on that cylinder in the cascade to isolate the leak from the balance of the tanks. The relief valve was later replaced.

4.5.7 Static Electricity Ignition of Venting CNG

A fire occurred during the calibration of a CNG dispenser. The calibration procedure involved filling a portable cylinder from the dispenser and weighing the portable cylinder to ascertain the mass of gas dispensed. The portable cylinder is then vented and the process is repeated. On this occasion, when the natural gas was being vented from 2,300 psig to atmospheric pressure, a fire occurred when the pressure was around 1500 psig. Since the jet of gas was directed towards the dispenser, the dispenser was extensively damaged. The fire was judged to have ignited from a static electricity discharge.

This incident is described in the December 1992 issue of Natural Gas Fuels magazine, p. 22.

4.5.8 CNG Bus Drive-Away and Fire

A driver fueled a paratransit bus at a CNG dispenser island in the morning before starting a morning run, but forget to disconnect the fueling hose. After driving about 12 feet there was a loud pop at the rear of the vehicle. The driver walked to the rear of the bus and heard a loud hissing sound of CNG escaping from the bus fuel system, which had just been pressurized to 3000 psig. The driver returned to the bus, shut off the engine and ran to a maintenance bay to tell a mechanic. About when the driver reached the maintenance shop, the escaping CNG ignited. The vehicle was totally destroyed and three others were damaged. The source of ignition was considered to be static electricity.

4.5.9 Propane Leak from Faulty Installation

A mechanic for a medium duty propane vehicle fleet found a small leak around the threads on the body of the valve on the propane vehicle fuel tank. The valve had a threaded connection which had not been tightened sufficiently. The leak was repaired by the upfitter who turned the fitting one more turn into the threaded tank connection.

APPENDIX A

SOURCES FOR ALTERNATIVE FUEL SAFETY INFORMATION

In addition to the specific references listed in "References - Section Three," the following sources contain more general information on alternative fuel safety:

General Information Hazard and Risk Analysis:

"Issues in Comparative Risk Assessment of Different Energy Sources," Sam Haddad and Adrian Gheorghe, International Journal of Global Energy Issues, Volume 4, 1992. p. 174.

General Information on Alternative Fuels:

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Alternative Fuels Training:

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Biodiesel:

"Biodiesel: A Technology, Performance and Regulatory Overview," National SoyDiesel Development Board report, February 1994.

Hydrogen:

"Hydrogen Vehicles: An Evaluation of Fuel Storage, Performance, Safety, Environmental Impacts, and Cost," M.A. DeLuchi, International Journal of Hydrogen Energy, Vol. 14, 1989. pp. 81- 130.

"Research on the Hazards Associated with the Production and Handling of Liquid Hydrogen," M.G. Zabetakis and D.S. Burgess," U.S. Bureau of Mines Report of Investigations 5707, 1961.

Electricity:

"An Illustrated Guide to Electrical Safety," William S. Watkins, Editor, American Society of Safety Engineers publication, 1983. [While not specifically directed towards electric vehicles, this publication contains a good summary of the principles of electrical safety as well as of relevant OSHA regulations.]

"National Electric Code," National Fire Protection Association, NFPA-70, 1993.

"Overview of EpideMiologic Research on Electric and Magnetic Fields and Cancer," David A. Savitz, American Industrial Hygiene Association Journal, Vol. 54, 1993, pp. 197-204.

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2. "Properties of Alternative Fuels," by M.J. Murphy, FTA Report No. OH-06-0060-92-5, U.S. Department of Transportation, Office of Technical Assistance and Safety (August 1992).

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