Topic Paper #21

An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation

On August 1, 2012, The National Petroleum Council (NPC) in approving its report, *Advancing Technology for America's Transportation Future*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

NATIONAL PETROLEUM COUNCIL
FUTURE TRANSPORTATION FUELS STUDY

An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation

White Paper

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CONTENTS

I. PURPOSE AND SCOPE

As part of the Future Transportation Fuels Study, the Natural Gas Subgroup has examined the potential expanded use of Liquefied Natural Gas (LNG) as an alternative to petroleum fuels.

As with any transportation fuel, LNG poses hazards and benefits. The purpose of this White Paper is to supplement the Study and discuss the history, risks and mitigating actions relating to deployment of LNG as a transport fuel from a safety perspective. To this end, the report will review each stage in the LNG transport fuel supply chain, identify the safety risks, consider technologies and standards in place to mitigate these risks, and seek to provide an objective analysis of the safety of LNG relative to existing transport fuels. The study will focus on deployment of LNG for medium- and heavy-duty vehicles as this is the area most targeted for LNG fuel use.

Given the described purpose, the report will not make specific recommendations on how to bridge perceived safety gaps, nor will it discuss the economics relating to installing and maintaining LNG safety measures. Scope is also focused specifically on transportation fuel infrastructure and equipment. The assessment of safety risks in the wider LNG industry has undergone numerous analyses and is therefore not in scope.

II. LNG PHYSICAL PROPERTIES

LNG is primarily methane with trace amounts of nitrogen and other hydrocarbons. The composition of LNG is slightly different from natural gas since compounds such as H_2O and CO_2 are removed before the liquefaction process. Therefore LNG can contain a higher percentage of methane gas when vaporized. If LNG is stored for long periods, methane's lower boiling temperature, compared to other hydrocarbons, causes the Methane portion of the LNG to decrease as Methane boils into the vapor phase in the storage tank, depleting Methane from the liquid phase in the tank. This "weatherization" process or enrichment means that if LNG is unused for sometime its composition can change.

Methane does not have a detectable smell. Distributed natural gas has sulfur compounds added to it so people can "smell leaking natural gas". These compounds are not added to LNG since the chemicals would typically freeze in the liquid. Equipment storing LNG (vehicles and fueling stations) have Methane detectors to detect leaks.

The advantage from making and storing LNG is that one cubic foot of liquid is equivalent to approximately 600 standard cubic feet of natural gas. The liquid phase can be a economic way to store large volumes of natural gas at relatively low pressure, increasing its volumetric energy density. LNG evaporates at -260^{o} F (at atmospheric pressure) and forms a visible cloud [due to condensation of moisture in the air] which is initially heavier than air until Methane vapor warms to -160^{o} F. A vapor cloud can persist at ground level temporarily until gas temperatures rise above -160^{o} F at which point the natural gas becomes lighter than air and dissipates. Natural gas is non-toxic but it is an asphyxiant when concentrated in sufficient quantities. If LNG contacts water, LNG is lighter than water and boils on top of water until it evaporates. As noted above, the vaporized natural gas cannot be detected through the sense of smell.

Natural gas burns with a visible flame. Natural gas has narrow flammability limits, combusting when in air/fuel proportions of 5-15%. Below 5% the mix is too lean to burn and above 15% the mix is too rich to burn. Pools of liquefied natural gas do not ignite as readily as pools of gasoline or diesel fuel. Methane gas' autoignition temperature is 1004^{o}F, significantly higher than gasoline (495^{o}F) or diesel (600^{o}F). As such, open flames and sparks can ignite natural gas; however, many hot surfaces such a car muffler will not. The flame front on burning methane in an open, unconfined environment has a very slow flame speed of about 4 mph.[i]

III. OVERVIEW OF THE LNG TRANSPORT INDUSTRY

The process of liquefying atmospheric gases was developed in the early 1900's and has been applied to the commercial production of liquefied natural gas since the 1940's. The earliest commercial use of LNG was in the US as a method of storing natural gas for "peak shaving", supplementing supplies to the pipeline infrastructure during periods of peak demand. In 2001, EIA estimates of total capacity at LNG storage facilities in the contiguous US (excluding marine facility storage) was 86 billion cubic feet (Bcf) and over 40 Bcf of LNG was added and withdrawn from storage over the course of the year. [ii] [iii] In its 2007 report, the Gas Technology Institute cited 53 operating LNG peakshaving plants with liquefaction units in the U.S.

International movements of LNG in large LNG tankers began in the 1960's and grew rapidly due to gas demand in Asian and European countries. In recent years, rising global gas demand and associated higher gas prices have driven significant further growth and diversification in LNG market consumers and suppliers. International deliveries of LNG were 220 million metric tons in 2010, equivalent to 29 Bcf/d. This international trade led to development of many safety standards. However, this business will not be addressed further in this report.

III.A. Brief Review Of LNG As A Transportation Fuel

LNG has been used as a transportation fuel since the 1970's, although in limited volumes for heavy-duty and fleet applications. In 2001, LNG vehicles accounted for only about 7.6 million gallons (about 2 per cent) of the 366 million gallons of alternative fuels consumed in the United States and a fraction of the 30 billion gallons of diesel consumed by freight trucks annually.[iv] [v] There are an estimated 7,000 vehicles with LNG fuel tanks operating in the U.S. today; public transit systems operate hundreds of LNG-fueled buses in Dallas, Phoenix, El Paso, Austin, Los Angeles and Orange County.[vi] LNG is also established and growing quickly as a transport fuel for short-haul, heavy-duty fleets. For example in June 2010, the Ports of Los Angeles and Long Beach announced the replacement of 800+ diesel drayage trucks with LNG trucks and, in April 2011, Heckmann ordered 200 LNG vehicles for its water services operations.[vii] [viii] Mining and refuse collection vehicles also represent major existing applications. LNG has also been used to fuel the LNG vessels engaged in international trade and in 20 other marine vessel applications (as of 2010) like ferries, offshore supply vessels and patrol vessels, outside of the U.S., predominantly in Norway. A future increase use of LNG as marine fuel on inland waterways and near-sea shipping is expected.

Imports of LNG or local LNG production for transportation fuel are currently performed throughout the U.S. These producers then contract the transportation of LNG fuel to approximately sixty-five refueling sites across the country to fleets with purpose-built cryogenic trailers. There are an estimated

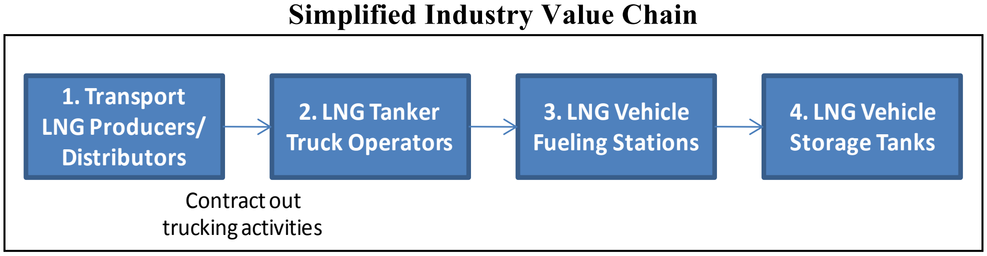
170 LNG transportation trailer trucks operating in North America and each truck has the capacity to deliver 9,000-13,000 gallons per load limited by maximum payload. Currently LNG vehicle use is heavily concentrated in California with 71% of US refueling facilities located in the state.[ix] It is estimated that at least 200,000 gallons/day of LNG were trucked into California in 2006.[x] National consumption in transportation has continued to increase with the addition of new LNG production sites such as Clean Energy's plant in Boron, CA which produces 160,000 gallons of LNG per day.[xi]

Refueling sites are almost all owned and used by transit fleet vehicles. Refueling is performed by trained personnel at the sites, either the drivers or refueling site employees. The sites can store 15,000-30,000 gallons on average[xii] in on-site cryogenic tanks. For refueling, LNG is fed into the vehicle fuel tank using cryogenic pumps. Access to LNG refueling sites is currently limited with the majority of sites either private or strictly controlled. A small number of "public" refueling sites are currently in operation (for example, two in Long Beach)[xiii] however these are tied to nearby fleet operations and require a company fueling card. As infrastructure is being built out to support regional LNG truck fleets, the model is shifting towards public access, mirroring traditional diesel truck stops (e.g., CH4 Energy station in Salt Lake City). Given LNG's focus on heavy-duty applications, most users will be professionals (rather than the general public) which will support training with some manner of key card access to assure safe practices are followed.

III.B. LNG Transport Fuel Companies

LNG fuel production and site development is performed by a number of specialist companies focused on alternative transport fuels and cryogenic liquids.

Simplified Industry Value Chain



Example Companies

1. Transport LNG Producers/Distributors
- Applied LNG Technologies (ALT)
- Clean Energy
- Southeast LNG
- Prometheus Energy
- GdF Suez

2. LNG Tanker Truck Operators
- Tri-Mac
- Transgas
- J.B.Kelley
- LP Transportation
- Southeast LNG

3. LNG Vehicle Fueling Stations
- Applied LNG Technologies
- Chart, Inc. (NexGen)
- Clean Energy
- Cryofuel Systems
- Cryostar
- CVA

4. LNG Vehicle Storage Tanks
- Chart, Inc.
- Cryogenic Fuels Inc
- Westport Innovations
- Taylor Wharton
- Ros Roca Indox

- General Physics

IV. LNG TRANSPORT EQUIPMENT

The equipment used to transport LNG is not unlike that for over-the-road distribution of other cryogenic liquids. Thousands of shipments of liquefied oxygen, nitrogen and other industrial gases are safely completed annually to hospitals, manufacturers and other users in our communities. Compared to other cryogenic liquids, LNG has a higher boiling point (-260 degrees F) than liquid oxygen (-297F), liquid nitrogen (-320F) or liquid hydrogen (-420F), but LNG transportation systems draw from the technology incorporated in the systems used to transport these other cryogenic liquids.

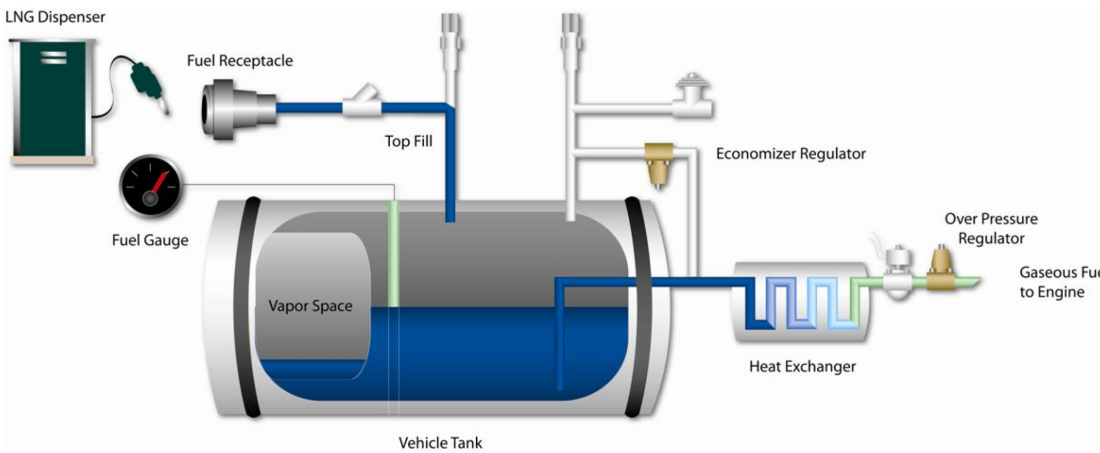
IV.A. Bulk LNG Trailer Design

Bulk LNG transport trailers consist of two nested tanks that form a thermos bottle-like insulating vessel. The inner tank may be stainless steel or aluminium; the outer tank must be steel (typically carbon or stainless steel). The space between the inner and outer tank is evacuated and filled with an insulating material such as multi-layer super insulation ("MLI" or "SI"), fiberglass, or, on older units, expanded perlite. The combination of the insulating material and the vacuum greatly reduces the heat flow from the relatively warm ambient environment to the cryogenic LNG. This keeps the LNG liquefied and the system pressure low for a long enough period of time to transport and unload the fuel, typically no more than 7-10 days. This double layering of metal tanks and structural supports make the overall tank extremely robust to physical damage and the effects of external fire. LNG trailers built in the U.S. comply with Department of Transportation design standards DOT CFR49 specifications– 49 CFR parts 173.318 and 178.338 (MC-338). This standard is used for trailers carrying cryogenic liquids, such as LNG, Liquid Nitrogen and Liquid Oxygen and there are manufacturers who specialize in supplying such equipment.

Although insulation reduces heat transfer, there will invariably be some heat transfer and the LNG will continuously boil, raising the vapor pressure in the storage tank. Tests have demonstrated that LNG trailers typically retain structural integrity up to 280psi (this value is calculated as tank burst), however trailers often have a design pressure of less than 100 psig and normally operate at pressures of less than 70 psig. Should the tank pressure exceed this level, a pressure release device (PRD) will safely release gas through an outlet pipe to the atmosphere. Venting of LNG trailers is rare in normal operations since the hold time of a trailer vastly exceeds the normal delivery time of one day. Redundancy is built into this pressure relief system through a secondary pressure release device with a pressure limit normally set 30-50% above the primary device pressure limit and well within tank safety design standards.

IV.B. Vehicle Fuel Tank Design

Similar to bulk trailers, LNG vehicle fuel tanks consist of two stainless steel tanks with vacuum insulation to increase the LNG storage time before the gas phase reaches the system relief pressure. This double-walled steel structure makes them considerably stronger than standard diesel fuel tanks. The continuous boiling off of methane raises the tank's pressure to the system's normal operating pressure of about 150psi but the insulation keeps the LNG liquefied and the system below the relief pressure for a useable period of time. After LNG flows from the tank, it is heated by a heat exchanger to form vapor, which is then regulated to the proper pressure (generally 75-120 psi) before it enters the engine. As with bulk transport trailers, if the pressure in the fuel tank exceeds the maximum allowable working pressure (MAWP), which is normally 230psi, a pressure relief device should safely release methane gas to the atmosphere. Also as in bulk trailers, a backup secondary pressure release device with a higher activation pressure will release through a separate release system.[xiv] Tests have shown that LNG fuel tanks can withstand pressure of up to 1100psi (calculated value), well above their maximum allowable working pressures. To further ensure the safety of these tank designs, sample tanks are subjected to destructive testing such as drop tests, where the tank is filled with liquid nitrogen and dropped from 10ft and 30ft and must not leak, and flame tests, where the tank is filled with Liquid Nitrogen or LNG and subject to a fire for at least 20min to ensure that during a fire the tank will not rupture.



Source: Chart, Inc.

Large vehicles with frame rail mounted tanks can hold up to 300 gallons of LNG. Most natural gas engines can use either LNG or CNG as a fuel source. LNG is typically used in medium/heavy duty applications where the higher fuel density compared to CNG maximizes driving range while minimizing weight and space required for fuel storage. For light-duty vehicles, LNG is not expected to be used due to a more limited number of LNG fueling stations and the fact that smaller capacity CNG tanks can hold sufficient fuel to provide adequate driving range.

V. CODES, STANDARDS AND REGULATIONS

V.A. Codes and Standards

The National Fire Protection Association (NFPA, www.NFPA.org) released the first LNG standard in 1967, titled *NFPA 59A Standard for the Production, Storage and Handling of Liquefied Natural Gas*. Since then, new codes and standards have been developed and existing codes updated to cover many areas of the LNG supply chain. Codes and Standards for LNG Vehicles have been in place since 1996's *NFPA 57 Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code,* which has been incorporated into NFPA 52 since 2005.These standards are promulgated to help the jurisdictions having authority over designs affecting public safety, such as local fire marshals and state regulators, to have references.

A listing of published standards includes:

- NFPA 52 Vehicular Gaseous Fuel Systems Code, 2010
- NFPA 59A Standard for the Production, Storage and Handling of LNG, 2009 edition
- SAE J2343 Recommended Practices for LNG Powered Heavy-Duty Trucks, 2008 Edition
- SAE J2645 LNG Vehicle Metering and Dispensing Systems, 2009 Edition
- SAE J1740 LNG Vehicular Fueling Connectors - *Status: On hold waiting for consensus building between manufacturers*
- SAE J2699 LNG Fuel Quality - *Status: Released in 2011*
- SAE J2700 LNG Fuel Tank - *Status: Task group reformed and work in progress - 2012*
- ASME Section VIII Division 1 Boiler and Pressure Vessel Code
- ASME B31.3 Process Piping
- 33CFR Part 127 Waterfront Facilities Handling LNG and Liquefied Hazardous Gas
- 49CFR 178.57 4L Welded Cylinders Insulated
- 49CFR Part 193 Liquefied Natural Gas Facilities: Federal Safety Standards
- 49CFR 178.338 (MC338) Insulated Cargo Tank Motor Vehicle
- California Title 8, Division 1, Chapter 4.1 LNG Storage Tanks
- California Title 13, Division 2, Chapter 4.2 LNG Fuel Systems
- API 620 Design and Construction of Large, Welded Low Pressure Storage Tanks
- NFPA30A – Code for Motor Fuel Vehicle Dispensing Facilities and Repair Garages 2010 Edition.
- ISO PC252 (ISO16924, ISO 12617, ISO 12614, and ISO 12991), Natural Gas Fuelling Stations for Vehicles - LNG Stations for fuelling Vehicles, Scope: Standardization in the field of design, construction and operation of natural gas fuelling stations for vehicles; including equipment, safety devices and maintenance. (In progress)

In 2010, the National Fire Protection Association (NFPA) released an updated version of NFPA 52: Vehicular Gaseous Fuel Systems Code. The document provides a detailed set of codes and standards for all vehicular gaseous fuel systems, including detailed sections on LNG vehicles, fueling stations and fire protection. This document provides clear standards for:

- The performance, installation, inspection, and testing of LNG fuel supply systems for vehicle engines
- The performance, siting, construction, installation, spill containment, and operation of containers, pressure vessels, pumps, vaporization equipment, buildings, structures and associated equipment used for the storage and dispensing of LNG and L/CNG as engine fuel for vehicles of all types
- LNG fire protection, personnel safety, security, LNG fueling facilities and training for LNG vehicles, and warning signs

V.B. <u>Local Regulations</u>

Safety concerns regarding LNG storage and transport have led some local municipalities and regions to implement laws and prohibitions regarding LNG manufacturing, storage, and transportation. The most notable is New York City where a moratorium on the siting of LNG facilities and intrastate transportation routes existed from 1973 to 1999.[xv] Specific permits regulating manufacture, storage, transportation, delivery and processing of LNG are still required within the Rules of the City of New

York. The city of Savannah, Georgia has also requested that the NHTSA review LNG tank truck safety due to a proposal to move multiple daily truck loads through parts of the city.

VI. SAFETY CONSIDERATIONS FOR LNG USE IN TRANSPORTATION

As with any fuel, LNG poses a number of potential hazards to health and property. Some of these are common to any transport fuel, such as combustion, while others are unique to LNG, such as cryogenic burns. The risk assessment portion of this paper will identify situations in using LNG as a transport fuel where the possibility of these hazards is elevated.

VI.A. Fire

If LNG is released from an insulated container to the ground, the LNG will flow downhill and begin to vaporize. Initially, the gas creates a vapor cloud above the released liquid. As the gas warms up, it mixes with the surrounding air and begins to disperse. This cloud will ignite if it encounters an ignition source while at a concentration within its flammability range of 5-15% by volume. This may lead to a flash fire and a subsequent pool fire, similar to that of gasoline or diesel. The fire's thermal radiation could harm people and damage surrounding equipment and property. Because of the relatively low pressure of an LNG tank, liquid or vapors will not discharge from a tank puncture in a high velocity jet (as is possible with a CNG tank) meaning there is less risk of a jet fire or 'torch fire'. In the event that a leak occurs in a confined space where the methane vapors builds up to a 5-15% concentration, there is the risk of an explosion upon contact with a high temperature heat source. This combustion would be similar to a gas explosion from a traditional gas leak, such as an indoor gas explosion.

However, LNG in a tank does not have adequate oxygen to support combustion and there would not be a high temperature ignition source in the tank, so a spill could cause a fire without all of the contents of the tank igniting at once.

VI.B. Pooling and Brittle Failure

Any brittle fracture of structural steels would require that the material soak in cryogenic fluid for a period of time. Creating a standing pool of LNG is not easy. The liquid is always under some level of pressure. When it is ejected from a breach in a container a large portion of the liquid vaporizes before it can settle into a puddle of standing liquid. Initially the reduction in pressure forces some of the internal heat of the liquid to flash boil itself. This is a thermodynamic certainty for the liquid to establish itself at ambient pressures. This vaporizes between 5 and 25 % of the liquid depending on its initial pressure. The remaining liquid stream breaks up and atomizes in the air. This break up accelerates the heat transfer from the air and further evaporates another 15-20 % of the stream depending on the velocity. What remain lands on the ground. Before it can settle into a puddle, it must cool the surrounding ground to cryogenic temperatures. Depending on the thermal mass of the surroundings, this can quickly evaporate an additional 20-25% of the liquid. All of this happens as the mass is ejected from the breach. Usually the mechanisms of flash and atomization result in no liquid surviving to the ground. In rare cases a puddle will begin, but the net volume of any such puddle is a small fraction of the initial volume. This all means that the practical extended exposure to cryogenic temperature is limited. Direct liquid spray is a local concern and can create local cracking,

A diesel or gasoline spill has some additional risk due to the persistence of the spill. While LNG evaporates and disperses quickly, diesel and gasoline spills remain on the ground for a sustained period extending the duration of the safety risk. Gasoline spills, for example, will not have such vaporization but will create larger pools. The larger pool and its ability to run extends the range of the potential fire from the spill. This leads to a longer potential duration of a dangerous situation if left un-managed. Spills of diesel fuel often result in expensive clean-up measures to protect surface water and groundwater.

VI.C. Phase Change and Over-Pressure Considerations

The previous sections have noted that LNG offers greater fuel density than CNG. One cubic foot of LNG can be the equivalent of 600 standard cubic feet of gas. (One cubic foot of compressed methane at 3000 PSI is the equivalent of 236 standard cubic feet of gas). If the LNG container is heated so the outer tank fails, and the insulation fails and the tank's pressure relief devices fail, the inner tank is not structurally able to hold the gas contents at the resulting ambient or high temperature and the tank would fail. Different types of failures have been evaluated.

VI.C.1 Vessel Overpressure Failure

The transition of LNG to a gaseous state can, in certain situations, lead to an explosive event. These explosions relate to rapid phase transformation. It should be noted that as LNG is stored at low pressure (70 psi in trailers, 2-50 psi in stationary storage, and 230psi in fuel tanks vs. 3600psi for CNG fuel tanks), immediate explosion due to rapid pressure release from a tank puncture is not a credible danger. The LNG storage tank could fail due to overpressure (e.g., due to ambient heat gain boil off or due to external fire exposure). The size and number of pressure release devices and the safety factor in the strength of LNG tanks drives the probability of vessel failure due to overpressure to an extremely low risk.

VI.C.2 Rapid Phase Transition (RPT)

If LNG comes into contact with water, it will float until it vaporizes. If large volumes of LNG are released on water, direct water-LNG contact can lead to a burst of heat transfer and rapid LNG vaporization. The rapid phase transition (RPT) range from small pops to moderate explosions, large enough to potentially damage lightweight structures. Given the relatively small volumes of LNG involved and low potential LNG release rates spilled LNG coming into contact with a body of water such as a river or lake, the potential power of an RPT in LNG transportation is very small. Studies have shown that in order to have meaningful energy release from an RPT the leak rate must exceed 10,000 gallons per minute which is not credible scenario for the equipment being assessed in this report.[xvi]

VI.C.3 Boiling Liquid Expanding Vapor Explosion (BLEVE)

Often a BLEVE is associated with external fire exposure where the fire weakens the container holding a flammable liquid and heats the contents of the tank. One critical mitigating factor is the US requirement for containers to be insulated with materials that do not detach during fire. The design specifications of LNG tank insulation built to US standards require insulation jackets that remain in place during a fire. The low temperature nature of the LNG and the thermal isolation provided by the jacket are designed to keep the upper portion of an LNG tank from reaching critical temperature.

The behaviour of containers without appropriately designed insulation can make them more susceptible to BLEVE events:

The pressurized liquid in an un-insulated container will boil, increasing its vapor pressure. The un-insulated nature of the vessel and the lack of the thermal mass of liquid on the top of the tank allows the upper portion of the vessel wall to increase in temperature which reduces its strength. If the temperature of the material gets above a critical level, the container fails causing the vessel's high pressure vapor to be released. The rapid phase change can create an explosive pressure surge which shatters the container. That localized failure causes the rapid pressure reduction and subsequent phase change and pressure surge. The leaking fuel then helps feed the fire. As discussed elsewhere, the pressure relief devices (PRDs) should be sized to keep the pressures inside the tank from exceeding the allowable limits specified by the vessel code, reducing the chance of such events.

There was an incident in Spain where a foam insulated single-walled LNG trailer exploded during a fire. In this incident the insulation did not remain in place during the accident and fire, likely contributing to the severity of the incident. U.S codes and design standards concerning insulating material and the application of double-walled trailers for transporting LNG are intended to mitigate against these failure modes.

VI.C.4 Vapor Cloud Explosion (VCE)

If a flammable vapor cloud accumulates in a highly congested area (or a confined area) and the cloud is ignited the combustion process can be so rapid that an explosion pressure wave is created. Such explosions typically require large vapor clouds and substantial congestion to create blast pressures that would injure people or damage property. Large ignited vapor clouds that are in the open, for example on a street, will not generate blast pressures, but the same cloud in a more contained area, say a heavily wooded area with a lot of undergrowth, could do so. A VCE also requires a fast flame speed or flame reactivity. Methane classifies as one of the least flame reactive hydrocarbons and does not detonate in open air.[xvii][xviii]

VI.D. Cryogenic Burns/Frostbite

LNG and cold vapor clouds can cause cryogenic burns or frostbite to unprotected skin in the event of a large leak. In addition, insufficient insulation could cause metal equipment to reach very low temperatures and direct contact with these parts could harm bare skin. Proper design and maintenance ensure sufficient insulation of pipes and equipment to avoid injuries caused by contact with cold surfaces. Ice or frost may form on cold equipment to warn of such a hazard. This is comparable to the risk of high-temperature burns through contact with the exhaust of a traditional engine if its insulation failed. Macro Technologies currently supplies LNG Quick Connect Nozzles for refueling vehicles.[xix] The equipment should permit fueling connections without leaking of LNG. The handles on the nozzle should not cause cryogenic burns. Even so, the company urges that the operators be familiar with the station safety procedures and that the fueler wears: full face shield; thermal gloves approved for cryogenic use; a cryogenic smock (to keep splashed liquid off clothes) and solid shoes capable of withstanding cryogenic spills. Maintenance of LNG fuel systems in particular requires training specific to cryogenic systems since there is a higher probability of contacting cold liquid or gas during maintenance activities than in normal operation.

VI.E. Environmental Effects

LNG spills completely evaporate leaving no residue that could harm ground water or waterways. LNG spills and natural gas venting would result in a release of methane to the atmosphere resulting in greenhouse gases that needs to be minimized during normal operation.

VII. LNG SAFETY INCIDENTS

VII.A. Historical Incidents

LNG has been produced and transported for many years and the industry has maintained an enviable safety record. It is a reflection of the relative safety of LNG fuel that so few incidents led to spillage and so few of these resulted in fire.[xx] LNG bulk storage has not had a major safety incident since the 1970's, and ongoing development of codes and standards has continued to improve safety. In bulk marine transport, eight marine incidents have resulted in spillage of LNG, causing some hull damage due to cold fracture but no cargo fires.[xxi] Seven other marine transport incidents not involving spillage – two from grounding – have been reported with no significant cargo loss. LNG carriers are, by design, much more robust than typical fuel and chemical tankers.

Opponents of LNG often reference the 1944 Cleveland LNG storage tank failure (*see Appendix A*) as a case against LNG projects. It is therefore worth noting this case's relevance to a modern assessment of LNG safety for use as a transportation fuel. Following the accident, an investigation by the Bureau of Mines concluded that the storage tank failed due to improper design, such as using wood supports for the inner tank and steel which was subject to brittle failure (3.5% nickel steel) due to material shortages during the War. The failure was exacerbated by insufficient secondary containment measures and the siting of the plant. Since this time, codes and standards have been developed to ensure suitable equipment and materials are used and that sufficient safety measures are in place. With particular reference to transportation fuel use, it should also be noted that the Cleveland spill involved a tank with a capacity of 1.3 million gallons of LNG, far in excess of even the largest tanker trucks (13,000 gallons) and refueling sites.

VII.B. Example Vehicular Incidents

For road LNG transportation, 20-30 public safety incidents have been reported since 1971 in the US and Europe. Almost all incidents were vehicle crashes, some involving violent collisions. It is a reflection of the design and safeguards of the tanks that less than half led to any loss of cargo and of these, only two led to fires. Another notable feature is that no-one except the driver of the vehicle has been seriously injured. [xxii]

The most significant LNG transportation incident identified occurred in June 2002 in Tivissa, Spain. An LNG tanker truck rolled over, causing a portion of the LNG tank insulation to become dislodged; a diesel fuel fire immediately ignited outside the LNG tank and after approximately 20 minutes a small explosion occurred, followed by a much larger explosion. The design of the trailer involved was very different from that required by US standards. It was a simple pressure vessel insulated with unprotected combustible polyurethane insulation, whereas cryogenic trailers in the US are double-walled, vacuum-jacketed pressure vessels with a steel outer tank. The diesel fuel fire caused the LNG tank to overheat and fail (the insulation was not effective because it was either knocked off or rapidly burned off).[xxiii] Although the Major Hazardous Incident Data Service (MHIDAS) database did not record the incident as a BLEVE, LNG risk assessment experts such as Pitblado accept “that this had features of a classical BLEVE and there is no inherent property of LNG excluding BLEVE-like events.”[xxiv] The Tivissa incident demonstrates the potential of a BLEVE; however Pitblado also pointed out that US LNG trucks built under the U.S. DOT specification MC338 would be highly unlikely to BLEVE due to design features.

In December 1992, a methane explosion occurred inside an LNG-powered 60-foot articulated bus during servicing. The vehicle 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 onboard the vehicle sounded an alarm. Although such repairs are supposed to be performed outdoors, because of inclement weather, the mechanic did the work in a normal bus repair bay. After becoming aware of the leak, he used a switch to override the alarm and start the bus in order to move the bus 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. The mechanic was unharmed.[xxv] The incident clearly highlights the importance of training and following of safety procedures.

The images below demonstrate the robustness of LNG fuel tanks to external fire and physical impact that has been witnessed in the field. The following images are from an accident in Australia involving an LNG-fueled truck which rolled over, severely damaging the vehicle cab. As can be seen in the pictures, the LNG fuel tanks, which are mounted on a gantry at the back of the cab, were not penetrated and suffered only external damage.

Source: Chart, Inc.

The images below are from an LNG-truck in California with side-mounted fuel tanks. The truck rolled onto its side, causing significant damage to the truck. The LNG tanks were undamaged in the incident.

Source: Westport Innovations

In 2008, a Polish LNG bus on a test ride caught fire due to the cracking of a hose carrying hydraulic oil which ignited in the engine space. The fire spread to the inside of the bus which burned out completely. The engine and neighboring LNG tanks were in the hottest part of the fire where temperatures were hot enough to melt aluminum materials. The LNG tank and safeguards functioned as designed, releasing its methane through the primary and secondary pressure relief devices which ejected the gas in a safe direction. The gas combusted but did not add to the burning of the bus itself and the tanks depressurized without any explosive activity.[xxvi]

Source: Solbus

These incidents reflect some of the worst of what has happened in forty years of using LNG as a transportation fuel and should be taken in context, comparing to gasoline and diesel tanker incidents. A survey of diesel tanker incidents shows a number of accidents, involving collisions and roll-overs, which have led to large fires and loss of life.[xxvii] This is due to both the larger number of such vehicles on the road, and the lower strength of the fuel storage tanks.

VII.C. Public Education

For the general public the properties and relative hazards of LNG are not understood. In many instances the local media has been the only source for educating the public when there is an incident where a LNG vessel may be involved or in the backdrop. The details of such incidents and role of LNG in the incidents is often not properly reported to the public but rather gives an unrealistic view as to the hazards. It was noted that the safety response to an incident in Nevada in 2009 far exceeded the required safety procedures and media comments from fire safety representatives after LNG tanker incidents reflect a lack of understanding and training regarding LNG accident response.[xxviii]

As the use of LNG in the public arena continues to grow, media campaigns and Learning Aids should be developed to better educate the public on the specifics of LNG. This should be done by an Industry group teamed with experts on how best to educate the public.

VIII. ASSESSMENT OF RELATIVE SAFETY IN THE LNG TRANSPORT FUEL SUPPLY CHAIN

Assessing LNG safety as a transport fuel requires the identification of hazards and safeguards associated with each stage in the LNG supply chain. Since the public has accepted other fuel supply chains, a relative risk comparison between those and the LNG supply chain can be useful. In all examples provided, the relative assessment is qualitative only.

VIII.A. Safety Assessment of Highway Bulk (Trailer) Transportation

The movement of truckload volumes of transport fuel, using the public roads and highways raises a number of safety concerns due to the relatively large volumes of fuel in one vehicle.

Safety Risks

Tanker truck risks largely focus on either a high-impact crash or a mechanical failure leading to the release of the cargo (up to 13,000 gallons of LNG) into a public environment. The consequences could be a cryogenic LNG spill which may lead to injuries and property damage, a fire potentially causing injuries and property damage, or a vapor cloud fire.

Potential causes of loss of containment include:

- Tank/piping failure due to impact
- Tank/piping failure due to overpressure
- Material failure due to corrosion
- Material failure due to brittle fracture
- Piping failure due to vibration and/or thermal fatigue
- Operator error (e.g., leaving a valve open)

Multiple safeguards are employed to prevent those causes from resulting in a loss of containment. These include:

- Mechanical design requirements are specified in Codes and Standards. Tank designs are particularly robust. LNG tankers are double-walled with insulation and structural supports in the vacuum layer between walls. This double layering maintains LNG at cryogenic temperatures and also provides additional protection against punctures and weakening due to external fire exposure

- Pressure relief devices are placed on all sections of storage and piping equipment where LNG maybe held. These limit equipment operating pressure at safe levels and will safely vent gas if an overpressure occurs
- Inspection and maintenance. Regular inspections of safety devices and loading/unloading hoses are specified.
- Operating procedures and training. This covers not only the operation of the LNG equipment, but also safe driving practices

Emergency response in event of LNG release or LNG Fire

- Emergency response. In California, a training manual has been developed for fire fighters on how to deal with an LNG tanker spill including safety boundaries, dispersion and extinguishing of LNG fires. Emergency response providers in other areas also receive training to handle LNG trailer and vehicle issues.
- As deployment increases, continuous improvement of training for fire fighting departments along all transport routes will be critical to mitigating any incidents.

Safety Analysis and Comparison to Other Transport Fuels

While LNG tanker trucks have decades of safe operating experience, the potential for highway accidents or crashes is similar to that of tankers hauling diesel or gasoline. In comparison to diesel and gasoline tankers involved in traffic accidents, LNG fuel transport are advantaged in terms of physical rupture as the tanks are significantly stronger than those carrying traditional liquid fuels and are also double walled. This is reflected by the record to date compared to similar impacts for diesel trucks which have caused significant spills. As a particular example, in Massachusetts in 1998 an LNG tanker was hit by a car. In the incident, the tanker's diesel fuel tanks were torn open and ignited; however, the LNG vessel remained structurally intact after the collision or ensuing fire.[xxix]

This lower probability of a significant incident must be compared to the potential damage of an LNG spill compared to diesel or gasoline should a spill occur. In both cases a large fire is the most realistic danger in a major collision, the additional risk for LNG relates to the possibility of an explosive event if the evaporating gas encountered some form of containment.

Risk Tables
The following system is used in the tables below to assess the relative risk of the LNG fuel chain to fuel chains for diesel, gasoline, CNG, and LPG

Higher – greater relative risk due to potential higher consequences, or higher probability of the event
Similar – similar relative risk to use of other fuels
Lower – Lower relative risk due to lower consequences or lower probability of the event

Where risks are LNG-specific (direct comparison is limited) safety relative to overall use of other transport fuels in that stage of the supply chain is considered.

Risk	Relative Consequence	Relative Probability of Event	Risk Level
Large spill from road collision	Higher – • Fire injury to people and property • Cryogenic burns to people in contact with cold vapors/liquid • Risk of explosion if the gas is confined	Lower– • Evidence demonstrates extreme difficulty in rupturing tank to the level required for a large-scale incident • Requires confinement to create risk of explosion	Similar
Tank overpressure and failure due to Fire	Similar – • Fire could lead to overpressure build-up if Pressure Relief Systems fail	Lower– • US codes on steel outer tank, insulation and PRDs make fire exposure failure highly unlikely • Event must coincide with the failure of multiple PRDs	Lower
Small gas leaks due to piping failures and/or cracks	Higher than diesel and gasoline – • Higher pressure increase potential size of fire	Lower – • High Autoignition temperature • Better dispersion • To be significant would require combined failure of the tank and detection sensors • Leak most likely to occur away from an ignition source and point in a less-dangerous direction • Leak likely to dissipate rather than pool like diesel or gasoline	Similar

VIII.B. <u>Safety Assessment of Bulk delivery and Fuel Storage at Fueling Stations</u>

Refueling stations perform a similar function regardless of fuel. Variations relate to the location, nature and volume of fuel stored and the risks around fuel dispensing. LNG is viewed as more hazardous due to the large volumes stored above ground and the relative volatility of the fuel itself compared to gasoline or diesel. Since LNG spills can dissipate in the air relatively more safely than LPG due to the LNG vapours warming and becoming more buoyant than LPG, LNG may be viewed as safer than LPG. These variations mean additional safety measures are required beyond traditional safety measures present at gasoline and diesel refueling sites. Safety in performance and operation of LNG vehicular fuel systems and refueling facilities is addressed by NFPA 52, which requires a containment system to catch spills and establishes separation distances for any buildings or property lines. The relative danger of direct contact with LNG compared to diesel and gasoline also increases safety requirements around dispensing pumps. Therefore LNG systems are interlocked and contained such that LNG is never in contact with the atmosphere during refueling as is the case for diesel and gasoline refueling. Therefore

LNG should not come in direct contact with people, property or sources of ignition unless there is a significant system failure.

Potential causes of loss of containment or spills include:

- Tank/piping failure due to impact
- Tank failure due to loss of strength (caused by fire exposure)
- Tank/piping failure due to overpressure
- Material failure due to corrosion
- Material failure due to brittle fracture
- Piping failure due to vibration and/or thermal fatigue
- Operator error (e.g., leaving a valve open)
- Accident, operator error or equipment malfunction during fuel delivery and unloading
- Collision with on-site storage tank, dispenser
- Mechanical failure in tank, tanker offloading pumps, or refueling equipment leading to vapor leak or LNG spill
- Operator error or equipment malfunction during trailer unloading
- Underground leaks migration through electrical ducts or drainage pathways into a neighboring building (underground vapors find the path of least resistance which sometime results in explosion hazards into the buildings – has occurred in industry at CNG refueling facilities)

Multiple safeguards are employed to prevent those causes from resulting in a loss of containment. These include:

- LNG storage containers are double-walled with insulation in the vacuum layer between walls. This double layering maintains LNG at cryogenic temperatures but also provides additional protection against punctures
- Employees performing tanker fuel delivery to site wear appropriate protective safety equipment and follow a range of safety procedures to minimize risk
- Pressure relief devices are placed on all sections of storage and piping equipment where LNG maybe held. These allow safe release of any pressure build-up beyond acceptable levels
- Site-design standards have clear requirements for secondary containment. Sites must have dikes in place to contain spills up to full volume of the largest tank on-site
- Codes set a stand-off distance for other buildings of 50 ft for storage tanks with capacities between 15,001 and 30,000 gal and 75 ft for storage tanks with capacities between 30,001 to 70,000 gallons. Shorter distances are permitted with the approval of the Authority Having Jurisdiction
- LNG Dispenser separation distance of 20 ft from other fuel dispensers.
- Detection systems for methane, fire and cryogenic temperatures are required throughout the site and particularly in locations where gas could accumulate
- Dispensing pumps have a number of cut-off switches to ensure LNG will only dispense when the pump nozzle is correctly attached to the tank
- Dispensing is currently only performed by personnel who have received training in refueling and LNG safety
- Rated impact protection for all above ground equipment design based upon site risk assessment
- Underground electrical conduit seals prior to building entrance from underground piping leak

- Additional considerations - Operator checks of customer vehicles for certification documentation or tag of receiving cylinders. (Not a code requirement)
- Additional considerations - For public locations where LNG has minimal daily oversite, provide integrated emergency shutdown of all site operations, offload tanker pumps, and onsite pumping and ESD valves when a leak is detected by gas detectors on site or by push of any ESD button on site. – Not a Code Requirement.
- Auditable routine preventative maintenance and inspection in accordance with codes and manufacturers guidelines

Safety Analysis and Comparison to Other Fuels

Safety considerations for LNG stations differ from those associated with pipeline-supplied CNG stations. LNG stations will hold a greater inventory of natural gas in the station at any time than CNG stations; however the LNG is stored more stably at low-pressure in double-walled tanks rather than the high-pressure tanks in which CNG is stored.

The risks of LNG storage at LNG refueling sites are inherently higher since these tanks are typically above ground and gasoline and diesel tanks are typically underground, but comparable to LPG storage which is also above ground. These risks are mitigated through additional safety features such as increased separation distances (relative to gasoline and diesel), spill containment requirements, and methane gas detectors. Dispensing risk is similar to the process for CNG with both closed systems requiring a more secure fitting between the tank and the nozzle than gasoline or diesel and having similar risks relating to a seal failure (one releasing a high pressure jet of flammable gas, the other a low pressure flow of cryogenic liquid) which require cut-off devices.

Risk	Potential Scale of Damage	Probability of Event	Risk Level
Large spill during bulk delivery	Higher than diesel and gasoline – • Release of large volume of LNG from either tanker or site storage • Cryogenic burns to people in the immediate vicinity • Potential ignition of a large vapor cloud causing large fire Similar to LPG	Lower – • Redundant backflow prevention valves at tank inlet • Highly trained personnel • Containment mitigates risk of spilled LNG compared to a diesel spill • Numerous cut-off valves on both sides of transfer • Procedures in place, such as turning off possible ignition sources while LNG vapors dissipate	Similar Lower than LPG
Small spill during dispensing	High – • Cryogenic burns to person dispensing	Low – • Safer dispensing mechanism than diesel: sealed transfer, cut-offs • Trained personnel in protective attire where appropriate	Similar

		• Preventative maintenance of nozzle connections for worn or damaged seal or connector.	
Site large storage tank spill	Higher – • Release of large volume of LNG site storage • Cryogenic burns to people in the immediate vicinity • Potential ignition of a large vapor cloud causing large fire	Similar – • Above ground tank, increasing exposure to impact • Highly trained personnel limit risk of error • Site measures mitigate potential damage of spilled LNG. e.g. dikes	Higher
Small gas leak from equipment	Similar – • Leak from equipment connected to or close to storage tanks risks escalation of damage • Leak if undetected could form sufficient vapor cloud for fire • Leak from underground piping risk intrusion of vapors into nearby building through conduit.	Lower – • Would require failure of multiple gas sensors on site to coincide with leak event Requires conduit penetration seal offs.	Lower

VIII.C. Safety Assessment of Vehicle Fuel Storage Tanks

Compared to a tanker truck unloading, the potential hazard for a vehicle refueling is limited because of the smaller LNG volume involved in a single incident. Despite their smaller size, LNG fuel tanks can, however, produce significant spills in public locations. Vehicle fuel tanks are also more at risk of incidents than tankers due to the broader range of applications and risk of less well-trained personnel performing monitoring and maintenance in the field. The major safety concerns are similar to those of tanker trucks although the risk probability and scale of damage are significantly different.

Potential causes of loss of containment or spills include:

- Tank failure due to impact
- Tank failure due to loss of strength (caused by fire exposure)
- Tank failure due to overpressure
- Material failure due to corrosion
- Material failure due to brittle fracture
- Failure due to vibration and/or thermal fatigue
- Fitting on vehicle either defective, damaged in earlier refueling and not repaired, not compatible with the fueling station nozzle, covered by dirt and/or ice or not constructed for LNG use

Mitigating Technologies, Codes and Standards

- LNG cylinders are subjected to standard safety tests that CNG cylinders undergo, including burn, crash, and gunshot tests

- LNG tanks are pressure vessels that are much stronger than conventional diesel-fuel tanks, making a penetration of an LNG tank less likely than for a similarly mounted diesel tank.
- Sealed, pressurized system less prone to operator caused fuel spills than gasoline or diesel refueling may cause
- Fueling nozzles or pressure relief valves vent evaporating LNG to manage vehicle tank pressure (without necessarily venting to atmosphere)
- Sensors on the vehicle can identify methane leaks or temperature changes allowing shut-off
- Detailed operating codes are in place around use of LNG vehicles and procedures should a risk alert be raised
- As with CNG vehicles, strict codes for maintenance and monitoring of tanks exist. With CNG, a more publically-used fuel type, the majority safety incidents relate to failures due to tank installation or tank safety monitoring

Safety Analysis and Comparison to Other Fuels

LNG vehicle fuel tanks are considerably more robust than diesel or gasoline fuel tanks. They are also relatively less at risk of impact damage than a CNG tank due to the high pressure contained within a CNG tank and its single-walled container.

Risk	Potential Scale of Damage	Probability of Event	Risk Level
Spill from road collision	Higher – • Cryogenic burns to people within immediate vicinity • Gas burning people and property • Diesel presents similar risk • Possibility of explosion in certain situations	Lower – • Difficulty in rupturing tank to the level required for a large-scale incident • Pressure release devices will safely manage pressure build up	Similar
Heating of tanker contents	Higher – • Fire could lead to explosive pressure build-up if PRD system is somehow unable to relieve pressure	Lower – • US codes on tank insulation and pressure release devices make a BLEVE unlikely • Event must coincide with the failure of a both PRD	Similar
Failure of a pressure release devices (PRD)	Higher – • Failure to vent gas could lead to a dangerous pressure build up which in extreme cases could rupture violently	Lower – • Would require the failure of both PRD concurrently	Similar
Failure to detect a small fuel leak	Similar – • An undetected leak could cause asphyxiation in an enclosed space or fire causing burns and damage • Leak from a diesel or gasoline tank can cause fire too and has greater risk of pooling	Lower – • To be significant, would require the combined failure of the storage tank causing the leak and the methane sensors detecting the gas	Lower

Venting of vapor from vehicle tank	Higher - • LNG vehicle is expected to be stored outside or in facilities designed to collect and discharge methane vapor releases. Garage roofs would safely gather the lighter-than- air vapor and ventilation to vent diluted gas • LNG Vehicles should be stored in well ventilated areas, or outside, where gas releases cannot build up in enclosed spaces	Higher - • Venting from pressure relief devices on vehicles parked for prolonged periods is expected. The tanks could be emptied or the venting gas reclaimed or catalytically burned if a commercial vehicle is parked for prolonged periods	Higher-

IX. SUMMARY

The introduction of any new fuel into the transportation system should be treated with appropriate caution, and LNG should be accorded the same treatment. Codes and standards specifically focused on vehicular and station design considerations, transportation and dispensing, and emergency response procedures must be reviewed prior to use, and updated regularly as the industry expands.

1. The physical properties of liquefied natural gas differ significantly from gasoline and diesel and should be accounted for when assessing broader safety implications and protocols.

- LNG is lighter than water and boils on top of water until it evaporates.
- LNG evaporates at -260F at atmospheric pressure and forms a visible cloud due to condensation of moisture in air
- It is heavier than air until the vapors warms to -160F. A vapor cloud can persist temporarily at ground level until the temperature rises above -160F at which point it becomes lighter than air and dissipates.
- Prior to dissipation it is an asphyxiant, however the risk of combustion is lessened since natural gas will only burn in concentrations of between 5 and 15 %.
- The autoignition temperature of methane is higher than that of gasoline and diesel.
- LNG does not have ordorization applied and therefore only indication of presence of Methane from LNG release is visible liquid pool, a visible vapour cloud (condensing of water in air), icing of a leak point or the use of gas detectors if leak is small.

2. Like other transportation fuels, there is some risk of fire and explosion, but the combination of fuel properties and fuel system designs can reduce this risk.

- In the event of a tank failure, liquid or vapors will not discharge in a high velocity jet due to the relatively low pressures of LNG storage, reducing the likelihood of a jet fire or "torch fire".
- There is inadequate oxygen inside the tank to support combustion, so a spill could cause a fire without all of the contents of the tank igniting at once. The low pressure of LNG storage also precludes the possibility of an immediate explosion due to rapid pressure release from the tank, and the danger of overpressure is mediated by redundancies in pressure release systems.
- Rapid phase transition explosions are not possible for the volumes of LNG utilized within the transportation industry. Vapor Cloud Explosions are pressure waves which occur when flammable gasses accumulate in heavily congested areas and combust, but their probability is reduced with LNG as methane has one of lowest flame speeds of all hydrocarbons and does not detonate in open air.
- U.S. tank construction standards require all tanks to have insulation which will stay in place in the event of a fire, reducing the chances of a Boiling Liquid Expanding Vapor Explosion (BLEVE) occurring in the event of a fire.

3. The LNG vehicle industry is regulated with recent updates to key codes and standards governing LNG vehicles, fueling stations and fire protection adopted in 2010. There are a number of Society of Automotive Engineers (SAE) standards currently in review and development.

4. The on-road distribution of LNG makes use of the same vehicles and trailers as other cryogenic liquids. It is transported along the same highway network in accordance with regulations for hazardous materials.

- LNG transport tankers consist of two nested tanks that form an insulated vessel. This double layering of tanks and structural supports make the entire tank extremely robust to physical damage and the effects of external fires.
- The tanks are tested to function safely at much higher pressures than the relatively low pressure level they normally operate at, and make use of multiple backup levels of pressure release devices.
- LNG vehicle fuel tanks consist of two stainless steel tanks with vacuum insulation. The insulation increases the LNG storage time before the gas phase reaches the system release pressure. Like bulk trailers, there is redundancy built into the pressure relief system.
- All tank designs are subjected to sample destructive testing and flame tests prior to use to ensure they are not susceptible to physical compromise or fire damage.

5. The LNG industry has a strong safety record in the US, supported by updated codes and standards.

- The only significant LNG accident in U.S. history, in Cleveland in 1944, was the result of improper materials being used in tank construction as a result of the materials shortages related to the war effort, a clear contravention of current U.S. regulations for tank construction.
- For over-road LNG transportation, 20-30 public safety incidents have been reported since 1971, almost all of which were vehicle crashes, some involving violent collisions; yet of these less than half led to any loss of cargo, only two resulted in fires, and no-one but the driver of the vehicle was ever seriously injured.

6. Unlike spills of diesel and gasoline, LNG spills completely evaporate leaving no residue that could harm ground water or waterways. It is very difficult to create a standing pool of LNG.

7. LNG dispensing systems are designed to minimize or restrict the release of methane to atmosphere or the exposure of persons to cryogenic liquids.

- LNG should not come in direct contact with people, property, or sources of ignition unless there is a significant system failure. The risks of LNG storage at LNG refueling sites are inherently higher than those of traditional liquid fuels since LNG tanks are typically above ground whereas gasoline and diesel tanks are underground. These risks are mitigated through additional safety features such as increased separation distances relative to gasoline and diesel, spill containment requirements, and methane gas detectors. Dispensing risk is similar to the process for CNG with both closed systems requiring a more secure fitting between the tank and the nozzle than gasoline or diesel and having similar risks relating to possible seal failure which requires cut-off devices.

8. LNG refueling stations are primarily owned and operated by private fleets where refueling is performed by trained personnel, reducing the risk of incorrect fuel handling.

- A small number of public sites in California are tied to nearby fleet operations and require a company fueling card. Given LNG's suitability to Heavy Duty vehicle applications, most users will be professional drivers rather than the general public. This allows for training and restricted access via key cards to ensure safe practices are followed.
- There are currently approximately 7,000 LNG fueled vehicles in the U.S. in public transit systems in Dallas, Phoenix, El Paso, Austin, Los Angeles and Orange County. LNG is also established and expanding as a transport fuel for short-haul, heavy-duty fleets.

- LNG storage equipment including vehicles and fueling stations are required by code to be installed with minimal safety distances from buildings, gasoline refuelings, and property lines to mitigate incident in the event of a release. Spill containment and methane gas detectors are required to be in place on site.
- ISO Standards (PC 252) are in development for LNG Refueling Stations which will address safety in design and maintenance procedures considered for refuelling stations with minimal site staff, LNG fuel quality requirements, standardization for connection compatibility of all dispensing nozzle / vehicle receptors, and issues with vehicles requiring various delivery pressures.

X. APPENDIX A

Cleveland Incident[xxx]

Cleveland, Ohio, 1944

In 1941, the East Ohio Gas Company built a peakshaving facility in Cleveland. The facility operated without incident until 1944, when the facility was expanded to include a larger tank. A shortage of stainless steel alloys during World War II led to compromises in the design of the new tank which was produced using 3.5% nickel steel, known to be susceptible to cryogenic embrittlement. The tank failed shortly after it was placed in service releasing 1.3 million gallons of LNG. The LNG that escaped formed a vapor cloud that filled the surrounding streets and storm sewer system. Natural gas vapor in the storm sewer system was ignited. The Cleveland event resulted in the deaths of 128 people in the adjoining residential area. The investigating body, the U.S. Bureau of Mines, concluded that the concept of liquefying and storing LNG was still valid if "proper precautions were observed."

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