

The Transportation and Use of Natural Gas: Exploring Safety Concerns and the Risk-Reward Equation

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June 15, 2011

Overview

Natural gas is poised to play an increasingly important role in the future of the United States' energy economy. As the role of natural gas expands, natural gas in its liquid form, liquefied natural gas (LNG), will also play a critical role, as an economical way of transporting natural gas in a form that also provides an alternative fuel for marine vessels, vehicles and industrial consumers. The controversy and confusion surrounding the safety of the transportation, storage and distribution of natural gas emanates largely from lack of accurate information and often from a purposeful skewing of facts by interested parties. This is all the more true of LNG, which remains an enigma to the public and policymakers alike.

LNG tankers have been safely and securely operated over tens of thousands of voyages for the past sixty years, and LNG has been used as a marine fuel for the past decade with no major marine accidents or pollution incidents and significant air pollution and greenhouse gas reduction. Still, LNG is cryogenic and flammable, and like other similar liquids, there are legitimate safety concerns. This paper aims to both address the real safety concerns and hazards associated with LNG and to debunk common myths. As with any policy decision, both risks and rewards will be considered. This author feels that, in the case of LNG, the expected rewards outweigh the potential risks.

I. Physical and Chemical Properties of LNG

Analysts expect the demand for global energy to increase rapidly over the coming decades. Natural gas currently makes up about one quarter of the world's energy supply, and US demand for natural gas is expected to grow rapidly as petroleum reserves are depleted, especially given natural gas's domestic abundance. Converting natural gas (predominately methane) into its liquid form, liquefied natural gas (LNG), vastly reduces

its volume, and is thus useful for transportation and storage and ultimately for use as an alternative fuel. As a result, it is valuable to have a discussion about what LNG is and the real safety risks associated with its transportation and distribution.

LNG is produced by super-cooling natural gas into liquid form at roughly -260 degrees Fahrenheit, at atmospheric pressure. The liquid can be stored at a cryogenic facility, distributed (as liquid) for use as engine fuel, or transformed back into a gas and fed directly into pipelines and generating facilities.

The liquid itself, properly contained, poses little danger. LNG is non-toxic, non-corrosive, and odorless. In its liquid state it is non-flammable and incapable of resulting in an overpressure (explosion). LNG is not a pressurized substance like the propane used for barbeque grills or the butane that fuels lighters. Rather, it is a cryogenic liquid, meaning that it is in a liquid state by virtue of its extremely low temperature, not high pressure. Because of these physical and chemical properties, there are certain unique and specific safety concerns similar to those associated with the use of other high energy fuels and hazardous materials in our daily lives.

It is first important to note that physical contact with the freezing liquid will freeze the point of contact. Just as natural gas is less dense than air and will rise, LNG is less dense than water and when spilled on water will float. In general, if an LNG spill on water or ground does not encounter an ignition source, the LNG will warm and quickly vaporize into its gaseous state, ultimately rising and dissipating into the atmosphere. The resulting white cloud, while non-toxic, can be combustible. This cloud is not a result of the natural gas itself, but of the condensation of moisture in the surrounding air due to low temperatures.

Natural gas is combustible between five and fifteen percent by volume of gas to air. If the gas is too rich (above the upper flammability limit) or too lean (below the lower flammability limit), it will not ignite.ⁱ If the gas-air ratio is within the flammability range, an ignition source will cause the vapor cloud to catch fire. There is, however, no evidence

that such an ignition in an *unconfined area* would result in an overpressure (explosion). In fact, the probability that a vapor cloud would result in a major explosion is extremely remote. This is because, in contrast to gasoline which burns quickly and often leads to explosions, methane has a relatively high auto-ignition temperature (temperature at which the gas will ignite), relatively slow flame velocity (speed at which the gas will burn once ignited), and tendency towards flame quenching (tendency for a flame to self-extinguish).ⁱⁱ Nonetheless, the cold vapor cloud formed from an LNG release will remain heavier than air until the cloud reaches approximately -157 degrees Fahrenheit. At this temperature, the natural gas vapor will rise into the atmosphere and dissipate. This will occur within a relatively short period of time after a release of LNG.

When natural gas-related explosions do occur, they generally occur in confined or partially confined spaces, such as buildings. Damage from these explosions would likely be restricted to the immediate vicinity.ⁱⁱⁱ A form of explosion may also occur from LNG spillage on water, even when an ignition source is not present. If large volumes of LNG are released onto water, the LNG may vaporize too quickly and undergo a process called rapid phase transition, which would result in a physical vapor explosion (not a combustion). The explosion from rapid phase transition would be relatively small scale, with the maximum damage reported at an equivalent of 6.3 kg of TNT. By comparison, the 2000 attack on the USS Cole in Yemen used the equivalent of more than 300 kg of TNT. According to Sandia¹, the most significant threats to public safety occur within approximately 500 meters of a spill on water or on land, with lower effects on safety at distances beyond 1600 meters.^{iv}

II. LNG Safety Record

In over sixty years of commercial use, representing well over 45,000 LNG carrier voyages and traveling more than 100 million miles, the liquefied natural gas industry has actually had an exemplary safety record compared to petrochemical plants and refineries.^v This is largely due to the fact that the industry has developed systems and

¹ Sandia is a government owned, contractor operated engineering and science laboratory. The threats mentioned involve severe burns due to thermal radiation at 500 meters; by 1600 meters, while heat would be felt, this proximity would not result in skin burns.

procedures for transporting and storing LNG, from the engineering phase, to operations, to the codes and regulations that enhance public safety in the unlikely event of an accident. There are four essential layers of protection that are designed to ensure safety in the LNG industry. The first, called *primary containment*, means that LNG facilities and ships must use appropriate materials and engineering designs for the transportation and storage of LNG. This requires an in-depth understanding of how materials behave at cryogenic temperatures (eg. LNG storage tanks are to be constructed of materials tolerant of cryogenic temperatures such as nine percent nickel steel, stainless steel, or aluminum alloys). The second layer of protection, *secondary containment*, refers to procedures that ensure that if a leak or spill were to occur, the LNG can be fully contained and/or isolated from the public. *Safeguard systems*, the third layer of protection, are the procedures and practices that minimize and mitigate the hazards associated with an accident, like fire. These systems include several levels of alarms as well as back-up systems like emergency shutdown. The final safety requirement is *separation distance* from the public of LNG facilities, including safety and buffer zones around large LNG vessels and facilities.^{vi} These layers of security are present across the LNG production and supply chain, and, as a result, there have been very few major incidents resulting from the use of LNG.² As the market for smaller-scale transportation of LNG expands, comparable security measures and precautions are being developed for vehicles and vessels.

A. LNG Marine and On-shore Incidents

In the 50-plus years of LNG tanker operations FERC has identified eight marine incidents involving LNG spillage. None of these spills resulted from the rupture of cargo tanks,^{vii} no cargo explosions have occurred, and there have been no shipboard fatalities.^{viii} There have also been several incidents at onshore facilities directly related to the LNG process, five of which resulted in one or more fatalities (Cleveland, Ohio, 1944; Arzew, Algeria, 1977; Cove Point Maryland, 1979; Bontang, Indonesia, 1983; Skikda, Algeria, 2004). Of these five incidents, two occurred in the United States. Another notable domestic accident occurred in Staten Island in 1973, but since no LNG was

² Below is a discussion of those incidents involving LNG deemed “major”. For a detailed description of all recorded accidents involving the use of LNG, at on-shore facilities, on-board ships, and on the road, please see: http://www.ch-iv.com/pdfs/Safety History of International LNG Operations _Mar 2009_.pdf

present, it has been classified as a “construction accident.” Since these accidents, more stringent regulations have been adopted and enforced, but each of these cases is nonetheless worth examining.

In 1944 a tragic accident occurred at the world’s first commercial natural gas peak-shaving plant in Cleveland, Ohio. The incident resulted in the death of 128 people and injuries to an additional 225. The accident was the result of the failure of a storage tank, which released LNG and formed a vapor cloud that leaked into the sewer system, a confined space, and caught fire. A second tank failed after 20 minutes of exposure to the fire when the tank’s supports buckled, causing the tank to fall over and fracture, releasing more LNG. The failure of the first tank was due to the composition of the tank material, made of only 3.5% nickel-steel, which embrittles at cryogenic temperatures. Today, only suitable cryogenic materials, such as at least 9% nickel-steel, are mandated. This is the most lethal accident to date and has prompted modern safety standards, such as secondary containment and appropriate buffer zones around large facilities. As a result, there has not been a similar failure in the years since this incident.

Another accident, often cited as an LNG incident but in reality unrelated to the presence of LNG, occurred in 1973 at a peak-shaving plant in Staten Island, NY while workers were repairing the inside of an empty tank. An unknown source ignited the non-explosion proof irons and vacuum cleaners being used to clean the tanks. The fire caused the tank’s concrete dome to collapse, killing 40 construction workers. The New York Fire Department concluded that the accident was a construction accident, since there was no LNG present in the empty tank. By 1988, the New York Planning Board, determined that “the government regulations and industry operating practices now in place would prevent a replication of this accident.”^{ix}

A final domestic onshore accident occurred at the Cove Point, MD LNG receiving terminal in 1979. Vaporized LNG leaked through a defective electric cable connection feeding power to an LNG pump and traveled through an electric conduit into a building that was not fitted with gas detectors. The mixture of natural gas and air ignited, and the

subsequent explosion killed one person and seriously injured another. As a result of this accident, there were three major changes made to the Cove Point terminal, and these changes are now applicable industry-wide. There has not been a serious accident involving an LNG facility in the US since the Cove Point incident 32 years ago.

There have also been several international incidents at on-shore facilities. Although it is important to note that operational and regulatory standards outside of the US are different and often less stringent, those accidents directly related to the presence of LNG are briefly described below.

A first accident occurred in 1977 in Algeria, when an aluminum valve failed on contact with LNG's cryogenic temperatures. LNG was released on one worker, who later died from injuries sustained by the freezing temperatures. A post-accident analysis revealed that the wrong aluminum alloy had been used for a replacement valve.

Another accident took place in 1989 in Thurley, UK. A drain valve that had been improperly closed during operations allowed LNG to enter a vaporizer, where it was released into the atmosphere like a "high-pressure jet." The subsequent vapor cloud ignited, and the flash fire covered a space approximately 40 by 25 meters. While there were no fatalities, two workers received burns to their hands and faces.

In 1993 an accident occurred at a liquefaction facility in Indonesia. The accident was the result of an LNG leak from an open run-down line during a pipe modification project. The LNG entered an underground storm sewer system, where it underwent a rapid vapor expansion that ruptured the sewer pipes. There were no resulting injuries or fatalities.

The most substantial overseas accident occurred in 2004 at an LNG liquefaction plant in Algeria. The accident was caused by the leaking of a flammable hydrocarbon used to refrigerate LNG. The resulting explosion and fire destroyed part of the terminal, killed 27 people, and injured 72 others. No one outside of the plant was injured. A joint report by FERC and DOE cited the presence of local ignition sources within the plant, lack of

proper shutdown systems and lack of hazard detection devices. These are all safety issues that are addressed in US regulation, and, had they been in place in Algeria, this accident could have been prevented.

B. LNG Trucking Incidents

The LNG trucking industry has been free of any serious incidents for over forty years. In 1979 the Department of Transportation commissioned a study to assess the risks associated with the transportation of LNG by truck and give recommendations. The study concluded that the risks of LNG trucking were relatively low, but offered several recommendations to reduce potential risks even further. Since these recommendations have been adopted, the accident rate has dropped by 80 percent.^x Over the last 40 years well over 700,000 cargoes of LNG have been trucked across the US. There have been 40 LNG trucking accidents domestically, of which only four resulted in a loss of product, and only one resulted in a fire.^{xi}

The incident resulting in a fire occurred in September 2005 in Fernley, Nevada, when a 10,000 gallon tanker truck leaked product and the subsequent LNG vapor was ignited. Emergency responders, unaware of the properties of LNG and the design of LNG trailers, evacuated an unnecessarily large area for about three hours until the fire subsided.^{xii} Because the trailer performed according to its design, there was no loss of vacuum, and after minor repairs it was returned to service within a week. Authorities determined the cause of the leak to be human error.^{xiii}

Internationally, an LNG trucking accident occurred in 2002 in Tivissa, Spain, when an LNG tanker truck overturned and caught fire. While some accounts have recorded this incident as the first LNG-related “boiling liquid expanding vapor explosion (BLEVE)”, the official report does not site a BLEVE. Experts have concluded that the accident would not have occurred in the US, since US LNG truck tanks are double-walled, whereas the Spanish tank was single-walled. Despite the severity of this accident, there was no injury to the driver or the public.

III. LNG Safety Myths

Part of the problem of examining the safety concerns involved with LNG is that the industry has such a sterling safety record that the precise consequences of and technicalities surrounding a large-scale LNG spill remain unknown. As a result, consequence predictions continue to be a source of debate in both scientific and policy spheres.^{xiv}

According to modern risk analysis, risks are assessed as a function of four elements: (1) the probability of an event; (2) the hazards associated with an event; (3) the consequences of an event; and (4) the effectiveness of prevention/mitigation systems available to manage risk.^{xv} While several real safety concerns are discussed above, modern safety policies and practices have ensured that there is a very low probability of the release (leak or spillage) of LNG during normal operations.^{xvi} Furthermore, the extensive international and US regulations and operational protocols and procedures designed to prevent or mitigate accidental LNG release and the resulting hazards mean that while the potential exists for a catastrophic, worst case LNG accident, the probability of a release of LNG during normal operations is extremely low, and the probability of an ignition of subsequent vapor is even lower.

In addition, while the ignition of a natural gas cloud would certainly be a grave event resulting in the release of intense energy, the duration of the incident would be relatively short-lived. As stated previously, LNG vaporizes and is rapidly burned off into the air. Depending on the quantity of LNG released and the exact conditions under which it is released, such an event is best measured in terms of minutes, not hours. This is compared to other energy incidents, such as oil spills, where casualty events can last for days, weeks, and even months with the potential for severe long term environmental damage. Where LNG, like other liquid fuels, is found in proximity to the general public, the consequences of an unlikely release and ignition can be very effectively managed by keeping total volumes with the potential to be released as low as practicably possible.

Two safety myths related to LNG should be addressed. The first is that of a BLEVE, or a “boiling liquid expanding vapor explosion.” While there is nothing in the properties of LNG to suggest that a BLEVE would be impossible, there have been no documented cases of LNG BLEVEs.^{xvii} BLEVEs are common when dealing with flammable gases maintained as liquid under pressure, such as propane. (*NB: Remember, LNG is **not** a highly pressurized substance.*) Dramatic videos of BLEVE explosions are often mistakenly described as LNG-related events, but because LNG is carried as a cryogenic liquid at nearly atmospheric pressure, it is not subject to the physical conditions required for a BLEVE to occur. If, however, for any reason a BLEVE were to occur during LNG trucking operations, it is widely agreed that the standard US-regulated double-shell tank would be able to withstand the explosion. In terms of marine operations, it is not credible that a BLEVE could occur on an LNG tanker.^{xviii}

The second myth that is often propagated by those critical of the industry is that an LNG tanker is a floating bomb. LNG itself is not combustible, and in the eight marine incidents out of well over 45,000 voyages^{xix} involving LNG that have occurred over the past fifty years, no cargo fires or explosions have been reported. The related idea that has gained much attention since September the 11th, that an LNG tanker could be hijacked by terrorists and used as a bomb with the explosive power of a nuclear weapon, is similarly erroneous. Since 2001 government and industry have strengthened security measures for all critical energy infrastructure including LNG receiving terminals and tankers. However, even in the case of a hijacking, it is not credible for an LNG tanker blown up with explosives to act like an atomic bomb. Although LNG tankers do contain a substantial amount of energy, explosive damage is a function of the rate at which energy is released. A nuclear bomb is so destructive because it is designed to release all of its energy near instantaneously. The same would not be possible with an LNG vessel.^{xx}

An examination of the potential consequences of an LNG accident in light of the improbability of such an event, especially given the United States’ sophisticated prevention and mitigation systems, suggests that many of the risks commonly associated with LNG have been highly exaggerated. In fact, the production, storage, transportation

and use of LNG is as safe as (or safer than) that of any other commercial fuel. LNG has the highest auto-ignition temperature of any liquid fuel,^{xxi} and natural gas has lower flame velocities than other hydrocarbons.^{xxii} By way of contrast, fuels with lower ignition temperatures and higher flame velocities, such as gasoline and LPG, surround us in our daily lives with very few safety concerns and even fewer safety incidents.

Furthermore, in a risk-reward analysis of the use of LNG, this author maintains that the potential benefits outweigh the potential risks. The abundant international and domestic supply of natural gas affords us unparalleled pricing power, and the increased use of LNG as fuel in lieu of foreign oil will increase U.S. energy security, help us to meet increasingly stringent global and domestic environmental emissions standards, and lead to tremendous positive affects on public health, which is being threatened by current vehicle emissions levels.^{xxiii} According to the U.S. Environmental Protection Agency, the natural gas-fueled Honda Civic GX is the “cleanest internal-combustion vehicle on Earth,” and the U.S. Department of Energy website touts the many benefits of natural gas as a consumer-vehicle fuel.^{xxiv} An 18-wheeler consumes as much fuel in one year as roughly 40 cars.^{xxv} Were heavy-duty trucks to implement already existing technology and run on natural gas instead of diesel, reducing pollutant emissions by anywhere from 20-40 %, the benefits would be legion and substantial.

V. Conclusion

Today in America we face an energy crisis, with unsustainable oil prices and greenhouse gas emissions. We are not yet in a position to transition to an all-renewable, zero emission energy economy, and coal is simply not the answer. As demonstrated by the nuclear crisis in Japan and the BP fiasco in the Gulf of Mexico, no available source of energy is immune from risk in either the construction of required facilities or their day-to-day operations. It is the policies and regulations at the federal, state and local levels that are designed to manage these risks. The use of LNG certainly comes with potential hazards, from direct human contact with the cryogenic liquid to flammable vapor clouds. However, the safety record of the LNG industry suggests that current safety codes and practices can effectively manage the potentially serious consequences associated with the

use of LNG. In the risk-reward analysis, the benefits of increased use of natural gas and LNG, including a cleaner energy economy, attractive pricing-power, independence from foreign oil and the many subsequent, positive effects on public health must be considered in the equation.

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ⁱ DNV, “Greener Shipping in North America.” February, 2011:
http://www.dnv.com/resources/reports/greener_shipping_north_america.asp

ⁱⁱ Filippo Gavelli, “Liquefied Natural Gas Explosion Hazards – Are They Real?,” *Hydrocarbon World*, 2009.

ⁱⁱⁱ Ibidem

^{iv} Sandia Report, “Guidance on Risk Analysis and Safety Implications of a Large liquefied Natural Gas (LNG) Spill Over Water,” 2004.

^v Phil Bainbridge, VP BP Global LNG, LNG in North America and the Global Context, IELE/AIPN Meeting University of Houston, October 2002.

^{vi} The Center for Energy Economics, “LNG Safety and Security,” October 2003:

www.beg.utexas.edu/energyecon/Ing/documents/CEE_LNG_Safety_and_Security.pdf

^{vii} Blake Harrison, “Offshore Threats: Liquefied Natural Gas, Terrorism, and Environmental Debate in Connecticut,” *Annals of the Association of American Geographers*, March 2008.

^{viii} According to the US Department of Energy, referenced in

http://www.beg.utexas.edu/energyecon/Ing/LNG_introduction_10.php

^{ix} Ibidem

^x FERC, “Freeport LNG Export Project and BOG/Truck Project: Environmental Assessment,” March 2009.

^{xi} Arthur D. Little Study commissioned by Southern LNG, 2010.

^{xii} CH-IV International, “Safety History of International LNG Operations,” December 2006:
http://www.ch-iv.com/pdfs/Safety_History_of_International_LNG_Operations_Mar_2009_.pdf

^{xiii} The Center for Energy Economics, “LNG Safety and Security,” October 2003.

^{xiv} Blake Harrison, “Offshore Threats: Liquefied Natural Gas, Terrorism, and Environmental Debate in Connecticut,” *Annals of the Association of American Geographers*, March 2008.

^{xv} Sandia Report, “Guidance on Risk Analysis and Safety Implications of a Large liquefied Natural Gas (LNG) Spill Over Water,” 2004.

^{xvi} The Center for Energy Economics, “LNG Safety and Security,” October 2003.

^{xvii} Doug Quillen, Chevron Texaco Corp., “LNG Safety Myths and Legends,” May 2002.

^{xviii} Filippo Gavelli, “Liquefied Natural Gas Explosion Hazards – Are They Real?,” *Hydrocarbon World*, 2009.

^{xix} See endnote vii.

^{xx} Filippo Gavelli, “Liquefied Natural Gas Explosion Hazards – Are They Real?,” *Hydrocarbon World*, 2009.

^{xxi} The Center for Energy Economics, “LNG Safety and Security,” October 2003.

^{xxii} DNV, “Greener Shipping in North America.” February, 2011.

^{xxiii} For more information, see the American Lung Association in California, “The Road to Clean Air: Public Health and Global Warming Benefits of Advanced Clean Car Standards”:

www.lungusa.org/california.

^{xxiv} US DOE Website, “Alternative and Advanced Fuels”:

http://www.afdc.energy.gov/afdc/fuels/natural_gas_benefits.html

^{xxv} Jeffrey Ball, “Natural-Gas Trucks Face Long Haul,” *The Wall Street Journal*, May 17, 2001:

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