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LNG SAFETY AND SECURITY

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LNG SAFETY AND SECURITY[1]

EXECUTIVE SUMMARY

This briefing paper is the second in a series that describes the liquefied natural gas (LNG) industry and the increasingly important role that LNG may play in the nation's energy future. The first paper, ***Introduction to LNG***, briefs the reader on LNG and touches on many of the key issues related to the LNG industry. This paper's first edition came out in October 2003 and deals with safety and security aspects of LNG operations. A third paper, ***The Role of LNG in North American Natural Gas Supply and Demand***, followed in September 2004. All of these reports, with supplemental information, were compiled in a complete online fact book, ***Guide to LNG in North America,*** www.beg.utexas.edu/energyecon/lng.

LNG has been transported and used safely in the U.S. and worldwide for roughly 40 years. The U.S. has three types of LNG facilities: LNG export, LNG import, and LNG peaking facilities. The U.S. has the largest number of LNG facilities in the world, scattered throughout the country and located near population centers where natural gas is needed.

The LNG industry has an excellent safety record. This strong safety record is a result of several factors. First, the industry has technically and operationally evolved to ensure safe and secure operations. Technical and operational advances include everything from the engineering that underlies LNG facilities to operational procedures to technical competency of personnel. Second, the physical and chemical properties of LNG are such that risks and hazards are well understood and incorporated into technology and operations. Third the standards, codes, and regulations that apply to the LNG industry further ensure safety. While we in the U.S. have our own regulatory requirements for LNG operators, we have benefited from the evolving international standards and codes that regulate the industry. This report defines and explains how LNG safety and security is achieved, based on our extensive review of technical and operational data.

Safety in the LNG industry is ensured by four elements that provide multiple layers of protection both for the safety of LNG industry workers and the safety of communities that surround LNG facilities. **Primary Containment**[2] is the first and most important requirement for containing the LNG product. This first layer of protection involves the use of appropriate materials for LNG facilities as well as proper engineering design of storage tanks onshore and on LNG ships and elsewhere.

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[1] This publication was supported by a research consortium, ***Commercial Frameworks for LNG in North America***. Sponsors of the consortium were BP Energy Company-Global LNG, BG LNG Services, ChevronTexaco Global LNG, Shell Gas & Power, ConocoPhillips Worldwide LNG, El Paso Global LNG, ExxonMobil Gas Marketing Company, Tractebel LNG North America/Distrigas of Massachusetts. The U.S. Department of Energy-Office of Fossil Energy provides critical support and the Ministry of Energy and Industry, Trinidad & Tobago participates as an observer. The report was prepared by CEE researchers Michelle Michot Foss, Fisoye Delano, Gürcan Gülen, and Dmitry Volkov. Peer reviews were provided by university faculty colleagues and outside experts.

[2] The term "containment" is used in this document to mean safe storage and isolation of LNG.

Secondary containment ensures that if leaks or spills occur at the onshore LNG facility, the LNG can be fully contained and isolated from the public.

Safeguard systems offers a third layer of protection. The goal is to minimize the frequency and size of LNG releases both onshore and offshore and prevent harm from potential associated hazards, such as fire. For this level of safety protection, LNG operations use technologies such as high level alarms and multiple back-up safety systems, which include Emergency Shutdown (ESD) systems. ESD systems can identify problems and shut off operations in the event certain specified fault conditions or equipment failures occur, and which are designed to prevent or limit significantly the amount of LNG and LNG vapor that could be released. Fire and gas detection and fire fighting systems all combine to limit effects if there is a release. The LNG facility or ship operator then takes action by establishing necessary operating procedures, training, emergency response systems, and regular maintenance to protect people, property, and the environment from any release**.**

Finally, LNG facility designs are required by regulation to maintain **separation distances** to separate land-based facilities from communities and other public areas. Safety zones are also required around LNG ships.

The physical and chemical properties of LNG necessitate these safety measures. LNG is odorless, non-toxic, non-corrosive, and less dense than water. LNG vapors (primarily methane) are harder to ignite than other types of flammable liquid fuels. Above approximately -110^{o}C LNG vapor is lighter than air. If LNG spills on the ground or on water and the resulting flammable mixture of vapor and air does not encounter an ignition source, it will warm, rise, and dissipate into the atmosphere.

Because of these properties, the potential hazards associated with LNG include heat from ignited LNG vapors and direct exposure of skin or equipment to a cryogenic (extremely cold) substance. LNG vapor can be an asphyxiant. This is also true of vapors of other liquid fuels stored or used in confined places without oxygen.

There is a very low probability of release of LNG during normal industry operations due to the safety systems that are in place. Unexpected large releases of LNG, such as might be associated with acts of terrorism, bear special consideration although the consequences may well be similar to a catastrophic failure. In the case of a catastrophic failure, emergency fire detection and protection would be used, and the danger to the public would be reduced or eliminated by the separation distances of the facility design. LNG operations are industrial activities, but safety and security designs and protocols help to minimize even the most common kinds of industrial and occupational incidents that might be expected.

LNG contains virtually no sulfur; therefore the combustion of re-gasified LNG used as fuel has lower emissions of air contaminants than other fossil fuels. In crude oil producing countries, as a general move towards lessening the environmental impact of oil production, a larger percentage of the associated natural gas is being converted to LNG instead of being flared. In many instances, this choice reduces the environmental impact of the continuous flaring of large quantities of natural gas, while also capturing this valuable resource for economic use. Thus, LNG development can have significant environmental and economic benefits.

Importantly, the properties associated with LNG and the safety and security practices and regulatory oversight embedded in the industry system apply no matter what type of facility or end use. This paper focuses on LNG storage facilities that are associated with natural gas pipeline and utility operations and services, as well as the crucial infrastructure that comprises the global LNG "supply" or "value" chains. Demand for natural gas, in the form of LNG, is emerging and growing in the U.S., North America, and worldwide. Transportation constitutes one of the more quickly developing applications. LNG is used as fuel for regional and long haul trucking, truck operations at ports and harbors, railroads, and marine shipping (ferries and the like, as well as LNG ship operations). These uses require dispersed storage and distribution networks that, along with traditional satellite and peak-shaving facilities, can serve customers while meeting all safety and security requirements.

Our review of the LNG industry safety and technological record, engineering design and operating systems and the standards and regulations that governing the design, operation and location of LNG facilities indicates that LNG can be safely transported and used in the U.S. and North America so long as safety and security standards and protocols developed by the industry are maintained and implemented with regulatory supervision. Our LNG web site, http://www.beg.utexas.edu/energyecon/lng/, provides links to other industry, government, and public information sources.

INTRODUCTION

LNG has been transported and used safely in the U.S. and worldwide for roughly 40 years. The U.S. has the largest number of LNG facilities in the world, scattered throughout the country and located near population centers where natural gas is needed. Our analysis of data on LNG safety and security indicates an excellent safety record. This strong safety record is a result of several factors. First, the industry has technically and operationally evolved to ensure safe and secure operations. Technical and operational advances include everything from the engineering that underlies LNG facilities to operational procedures to technical competency of personnel. Second, the physical and chemical properties of LNG are such that risks and hazards are easily defined and incorporated into technology and operations. Third, a broad set of standards, codes, and regulations applies to the LNG industry to further ensure safety. These have evolved through industry experience worldwide and affect LNG facilities and operations everywhere. Regulatory compliance provides transparency and accountability. This report defines and explains how LNG safety and security is achieved, based on our extensive review of technical and operational data. Our conclusion is that LNG can continue to be transported, stored, and used safely and securely, as long as safety and security standards and protocols developed by the industry are maintained and implemented with regulatory supervision. It is in the best interest of the industry, regulators, and the general public that this goal be achieved so that the benefits of natural gas can be realized for consumers.

By converting natural gas to LNG, it can be shipped over the oceans and great distances from the countries where it is produced to those where it is in demand. Natural gas is used in homes for cooking and heating, in public institutions, in agriculture, by industry and to generate electric power. Natural gas is important not only as a clean source of energy, but also as a feedstock for the petrochemical industry to produce plastics, fibers, fertilizers, and many other products.

In this briefing paper, we discuss safety and security aspects of LNG. To prepare this report, we examined information on the physical properties of LNG, the safety record of LNG facilities and ships, the impact of the LNG operations on the environment and regulations and agencies concerned with safety and environmental protection in the LNG industry. Members of our team have visited LNG facilities in the U.S. and Japan. From this comprehensive review, we have concluded that LNG has been and can continue to be used safely. As shown in Figure 1 below, there is a continuous improvement of LNG safety, environmental and security infrastructure. This report outlines technologies, strategies, recommendations, and key considerations employed by the LNG industry, and by regulators and public officials charged with public safety and security.

Figure 1. Continuous Improvement of LNG Safety, Environmental, and Security Infrastructure

SAFETY CONSIDERATIONS IN LNG OPERATIONS

In order to define LNG safety, we must ask: *When is LNG a hazard?* The LNG industry is subject to the same routine hazards and safety considerations that occur in any industrial activity. Risk mitigation systems must be in place to reduce the possibility of occupational hazards and to ensure protection of surrounding communities and the natural environment. As with any industry, LNG operators must conform to all relevant national and local regulations, standards, and codes.

Beyond routine industrial hazards and safety considerations, LNG presents specific safety considerations. In the event of an accidental release of LNG, the safety zone around a facility protects neighboring communities from personal injury, property damage, or fire. The one and only case of an accident that affected the public was in Cleveland, Ohio in 1944 (See Table 4). Research stemming from the Cleveland incident has influenced safety standards used today. Indeed, during the past four decades, growth in LNG use worldwide has led to a number of technologies and practices that will be used in the U.S. and elsewhere in North America as the LNG industry expands.

Generally, multiple layers of protection create four critical safety conditions, all of which are integrated with a combination of *industry standards and regulatory compliance*, as shown in Figure 2.

Figure 2. Critical Safety Conditions

Industry standards are written to guide industry and also to enable public officials to more efficiently evaluate safety, security, and environmental impacts of LNG facilities and industry activities. Regulatory compliance should ensure transparency and accountability in the public domain.

The four requirements for safety – *primary containment, secondary containment, safeguard systems and separation distance* – apply across the LNG value chain, from production, liquefaction, and shipping, to storage and re-gasification. (We use the term "containment" in this document to mean safe storage and isolation of LNG.) Later sections provide an overview of the LNG value chain and the details associated with the risk mitigation measures employed across it.

Primary Containment. The first and most important safety requirement for the industry is to contain LNG. This is accomplished by employing suitable *materials* for storage tanks and other equipment, and by appropriate *engineering design* throughout the value chain.

Secondary Containment. This second layer of protection ensures that if leaks or spills occur, the LNG can be contained and isolated. For onshore installations *dikes and berms* surround liquid storage tanks to capture the product in case of a spill. In some installations a reinforced concrete tank surrounds the inner tank that normally holds the LNG. Secondary containment systems are designed to exceed the volume of the storage tank. As will be explained later, *double and full containment systems* for onshore storage tanks can eliminate the need for dikes and berms.

Safeguard Systems. In the third layer of protection, the goal is to minimize the release of LNG and mitigate the effects of a release. For this level of safety protection, LNG operations use systems such as *gas, liquid and fire detection* to rapidly identify any breach in containment and *remote and automatic shut off systems* to minimize leaks and spills in the case of failures. Operational systems (procedures, training and emergency response) also help prevent/mitigate hazards. Regular maintenance of these systems is vital to ensure their reliability.

Separation Distance. Federal regulations have always required that LNG facilities be sited at a safe distance from adjacent industrial, communities and other public areas. Also, safety zones are established around LNG ships while underway in U.S. waters and while moored. The safe distances or exclusion zones are based on LNG *vapor dispersion* data, and *thermal radiation* contours and other considerations as specified in regulations.

Industry Standards/Regulatory Compliance. No systems are complete without appropriate operating and maintenance procedures being in place and with insurance that these are adhered to, and that the relevant personnel are appropriately trained. Organizations such as the Society of International Gas Tanker and Terminal Operators (SIGTTO), Gas Processors Association (GPA) and National Fire Protection Association (NFPA) produce guidance which results from industry best practices.

The four conditions described above for safety, along with **industry standards and regulatory compliance**, are vital to continuing the strong LNG industry safety performance. They are essential if LNG is to play an increasing role in the U.S., both for energy security and to protect the flow of economic benefits from LNG to our society as a whole.

LNG PROPERTIES AND POTENTIAL HAZARDS

To consider whether LNG is a hazard, we must understand the properties of LNG and the conditions required in order for specific potential hazards to occur.

LNG Properties

Natural gas produced from the wellhead consists of methane, ethane, propane and heavier hydrocarbons, plus small quantities of nitrogen, helium, carbon dioxide, sulfur compounds, and water. LNG is liquefied natural gas. The liquefaction process first requires pre-treatment of the natural gas stream to remove impurities such as water, nitrogen, carbon dioxide, hydrogen sulfide and other sulfur compounds. By removing these impurities, solids cannot be formed as the gas is refrigerated. The product then also meets the quality specifications of LNG end users. The pretreated natural gas becomes liquefied at a temperature of approximately -256^{o}F (-160^{o}C) and is then ready for storage and shipping. LNG takes up only 1/600th of the volume required for a comparable amount of natural gas at room temperature and normal atmospheric pressure. Because the LNG is an extremely cold liquid formed through refrigeration, it is not stored under pressure. The common misperception of LNG as a pressurized substance has perhaps led to an erroneous understanding of its danger.

LNG is a clear, non-corrosive, non-toxic, *cryogenic*[3] liquid at normal atmospheric pressure. It is odorless; in fact, odorants must be added to methane before it is distributed by local gas utilities for end users to enable detection of natural gas leaks from hot-water heaters and other natural gas appliances. Natural gas (methane) is not toxic. However, as with any gaseous material besides air and

[3] Cryogenic means extreme low temperature, generally below -100^{o}F

oxygen, natural gas that is vaporized from LNG can cause asphyxiation due to lack of oxygen if a concentration of gas develops in an unventilated, confined area.

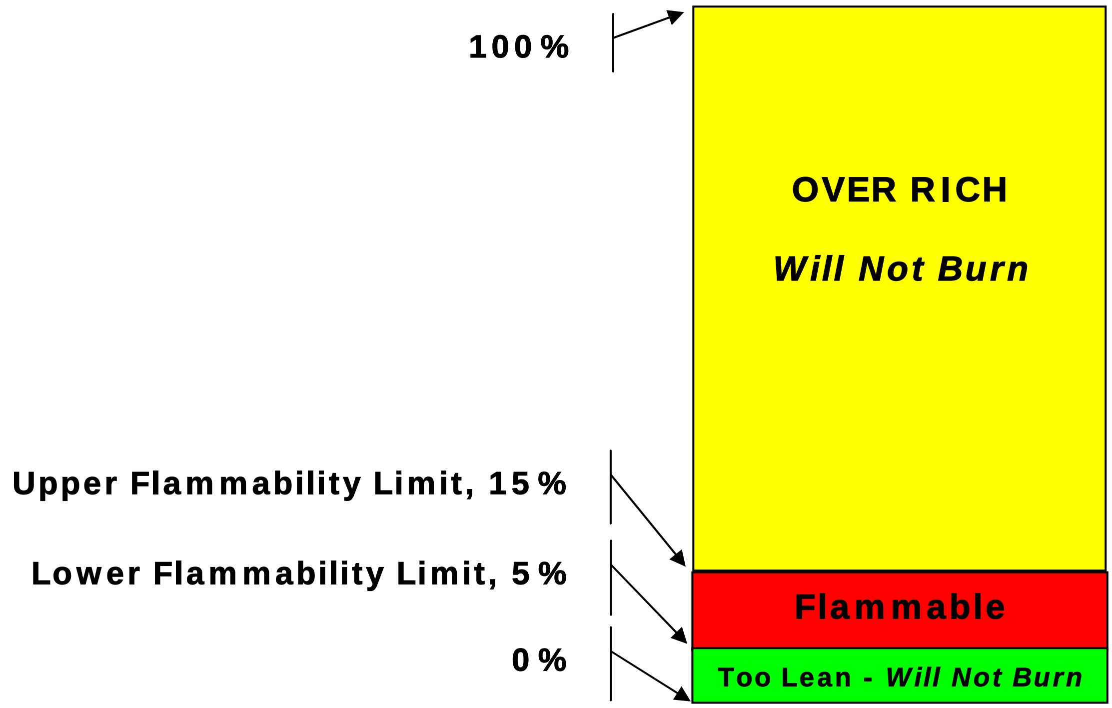
The *density* of LNG is about 3.9 pounds per gallon, compared to the density of water, which is about 8.3 pounds per gallon. Thus, LNG, if spilled on water, floats on top and vaporizes rapidly because it is lighter than water.

Vapors released from LNG as it returns to a gas phase, if not properly and safely managed, can become flammable but explosive only under certain well-known conditions. Yet safety and security measures contained in the engineering design and technologies and in the operating procedures of LNG facilities greatly reduce these potential dangers.

The *flammability range* is the range between the minimum and maximum concentrations of vapor (percent by volume) in which air and LNG vapors form a flammable mixture that can be ignited and burn.

Figure 3 below indicates that the *upper flammability limit* and *lower flammability limit* of methane, the dominant component of LNG vapor, are 5 percent and 15 percent by volume, respectively. When fuel concentration exceeds its upper flammability limit, it cannot burn because too little oxygen is present. This situation exists, for example, in a closed, secure storage tank where the vapor concentration is approximately 100 percent methane. When fuel concentration is below the lower flammability limit, it cannot burn because too little methane is present. An example is leakage of small quantities of LNG in a well-ventilated area. In this situation, the LNG vapor will rapidly mix with air and dissipate to less than 5 percent concentration.

Figure 3. Flammable Range for Methane (LNG)



A comparison of the properties of LNG to those of other liquid fuels, as shown in Table 1 below, also indicates that the Lower Flammability Limit of LNG is generally higher than other fuels. That is, more LNG vapors would be needed (in a given area) to ignite as compared to LPG or gasoline.

Table 1. Comparison of Properties of Liquid Fuels

Properties	LNG	Liquefied Petroleum Gas (LPG)	Gasoline	Fuel Oil
Toxic	No	No	Yes	Yes
Carcinogenic	No	No	Yes	Yes
Flammable Vapor	Yes	Yes	Yes	Yes
Forms Vapor Clouds	Yes	Yes	Yes	No
Asphyxiant	Yes, but in a vapor cloud	Same as LNG	Yes	Yes
Extreme Cold Temperature	Yes	Yes, if refrigerated	No	No
Other Health Hazards	None	None	Eye irritant, narcosis, nausea, others	Same as gasoline

Properties	LNG	Liquefied Petroleum Gas (LPG)	Gasoline	Fuel Oil
Flash point[4] (°F)	-306	-156	-50	140
Boiling point (°F)	-256	-44	90	400
Flammability Range in Air, %	5-15	2.1-9.5	1.3-6	N/A
Stored Pressure	Atmospheric	Pressurized (atmospheric if refrigerated)	Atmospheric	Atmospheric
Behavior if Spilled	Evaporates, forming visible "clouds". Portions of cloud could be flammable or explosive under certain conditions.	Evaporates, forming vapor clouds which could be flammable or explosive under certain conditions.	Evaporates, forms flammable pool; environmental cleanup required.	Same as gasoline

Source: Based on Lewis, William W., James P. Lewis and Patricia Outtrim, PTL, "LNG Facilities – The Real Risk," American Institute of Chemical Engineers, New Orleans, April 2003, as modified by industry sources.

Methane gas will ignite only if the ratio or mix of gas vapor to air is within the limited flammability range. An often expected hazard is ignition from flames or sparks. Consequently, LNG facilities are designed and operated using standards and procedures to eliminate this hazard and equipped with extensive fire detection and protection systems should flames or sparks occur.

The autoignition temperature is the lowest temperature at which a flammable gas vapor will ignite spontaneously, *without a source of ignition*, after several minutes of exposure to sources of heat. Temperatures higher than the autoignition temperature will cause ignition after a shorter exposure time. With very high temperatures, and within the flammability range, ignition can be virtually instantaneous. For methane vapors derived from LNG, with a fuel-air mixture of about 10 percent methane in air (about the middle of the 5-15 percent flammability limit) and atmospheric pressure, the autoignition temperature is above 1000°F (540°C). This extremely high temperature requires a strong source of thermal radiation, heat, or hot surface. If LNG is spilled on the ground or on water and the resulting flammable gas vapor does not encounter an ignition source (a flame or

[4] "Flash point" means the minimum temperature at which a liquid gives off vapor within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid. OSHA 1910.106. http://www.ilpi.com/msds/ref/flashpoint.html

spark or a source of heat of 1000°F (540°C) or greater), the vapor will generally dissipate into the atmosphere, and no fire will take place.

When compared to other liquid fuels, LNG vapor (methane) requires the highest temperature for autoignition, as shown in the Table 2.

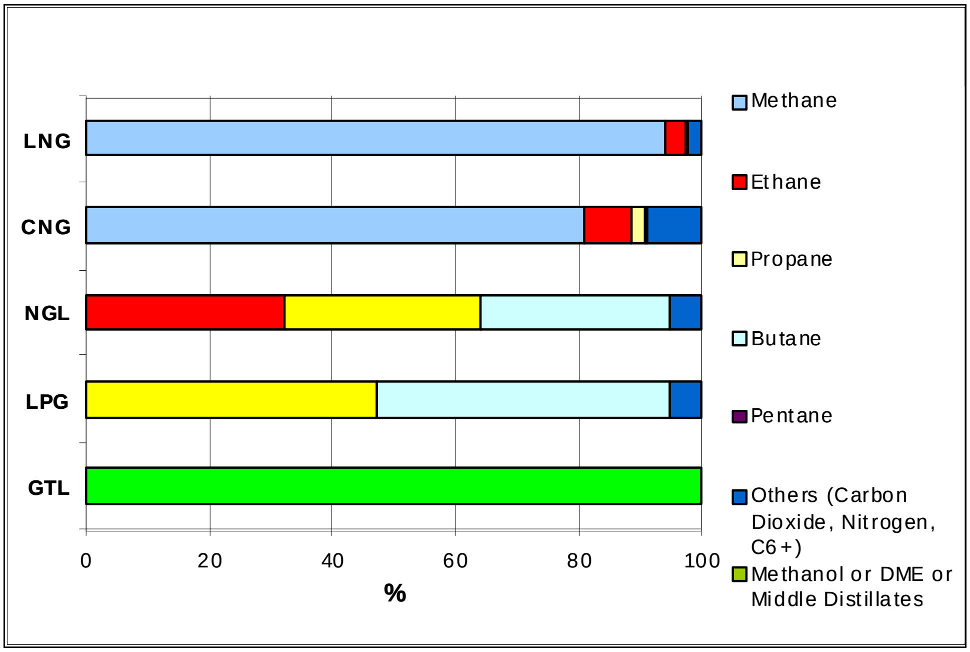
Table 2. Autoignition Temperature of Liquid Fuels

Fuel	Autoignition Temperature, °F
LNG (primarily methane)	1004
LPG	850-950
Ethanol	793
Methanol	867
Gasoline	495
Diesel Fuel	Approx. 600

Source: New York Energy Planning Board, Report on issues regarding the existing New York Liquefied Natural Gas Moratorium, November 1998

Questions about LNG safety often demonstrate how LNG is confused with other fuels and materials. Our first briefing paper, ***Introduction to LNG***, explains the differences between LNG and substances like liquefied petroleum gas (LPG), natural gas liquids (NGL). LNG is also quite different from gasoline, which is refined from crude oil. All of these fuels can be used safely as long as proper safety, security, and environmental protections are in place. In the U.S., we fill our cars and trucks with gasoline, use LPG (propane) in our backyard grills, and methane to heat our homes hundreds of millions of times each day, and serious safety incidents are rare. We can use both compressed natural gas (CNG) and LNG as transportation fuels. Natural gas can be converted to a middle distillate equivalent using Fischer-Tropsch; gas-to-liquids (GTL), while costly, would allow natural gas to flow directly into the petroleum value chain to provide transportation fuels and other products. All together, we transport and store all of these fuels and, again, safety and security incidents are rare.

Figure 4. Summary Comparison of LNG and Other Fuels



In summary, LNG is an extremely cold, non-toxic, non-corrosive substance that is transferred and stored at atmospheric pressure. It is refrigerated, rather than pressurized, which enables LNG to be an effective, economical method of transporting large volumes of natural gas over long distances. LNG itself poses little danger as long as it is contained within storage tanks, piping, and equipment designed for use at LNG cryogenic conditions. However, vapors resulting from LNG as a result of an uncontrolled release can be hazardous, within the constraints of the key properties of LNG and LNG vapors – flammability range and in contact with a source of ignition – as described above.

Types of LNG Hazards[5]

The potential hazards of most concern to operators of LNG facilities and surrounding communities flow from the basic properties of natural gas. Primary containment, secondary containment, safeguard systems, and separation distance provide multiple layers of protection. These measures provide protection against hazards associated with LNG.

[5] Much of the material in this section is taken from the New York Energy Planning Board *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.

Explosion. An explosion happens when a substance rapidly changes its chemical state – *i.e.*, is ignited – or is uncontrollably released from a pressurized state. For an uncontrolled release to happen, there must be a structural failure – *i.e.*, something must puncture the container or the container must break from the inside. LNG tanks store the liquid at an extremely low temperature, about -256°F (-160°C), so no pressure is required to maintain its liquid state. Sophisticated containment systems prevent ignition sources from coming in contact with the liquid. Since LNG is stored at atmospheric pressure – *i.e.*, not pressurized – a crack or puncture of the container will not create an immediate explosion.

Vapor Clouds. As LNG leaves a temperature-controlled container, it begins to warm up, returning the liquid to a gas. Initially, the gas is colder and heavier than the surrounding air. It creates a fog – a *vapor cloud* – above the released liquid. As the gas warms up, it mixes with the surrounding air and begins to disperse. The vapor cloud will only ignite if it encounters an ignition source while concentrated within its flammability range. Safety devices and operational procedures are intended to minimize the probability of a release and subsequent vapor cloud having an affect outside the facility boundary.

Freezing Liquid. If LNG is released, direct human contact with the cryogenic liquid will freeze the point of contact. Containment systems surrounding an LNG storage tank, thus, are designed to contain up to 110 percent of the tank's contents. Containment systems also separate the tank from other equipment. Moreover, all facility personnel must wear gloves, face masks and other protective clothing as a protection from the freezing liquid when entering potentially hazardous areas. This potential hazard is restricted within the facility boundaries and does not affect neighboring communities.

Rollover. When LNG supplies of multiple densities are loaded into a tank one at a time, they do not mix at first. Instead, they layer themselves in unstable strata within the tank. After a period of time, these strata may spontaneously *rollover* to stabilize the liquid in the tank. As the lower LNG layer is heated by normal heat leak, it changes density until it finally becomes lighter than the upper layer. At that point, a liquid rollover would occur with a sudden vaporization of LNG that may be too large to be released through the normal tank pressure release valves. At some point, the excess pressure can result in cracks or other structural failures in the tank. To prevent stratification, operators unloading an LNG ship measure the density of the cargo and, if necessary, adjust their unloading procedures accordingly. LNG tanks have rollover protection systems, which include distributed temperature sensors and pump-around mixing systems.[6]

Rapid Phase Transition. When released on water, LNG floats – being less dense than water – and vaporizes. If large volumes of LNG are released on water, it may vaporize too quickly causing a rapid phase transition (RPT).[7] Water temperature and the presence of substances other than methane also affect the likelihood of an RPT. An RPT can only occur if there is mixing between the LNG and water. RPTs range from small *pops* to blasts large enough to potentially damage lightweight structures. Other liquids with widely differing temperatures and boiling points can create similar incidents when they come in contact with each other.

Sloshing. The advent of LNG offshore terminals implies certain risks associated with tanks only partially filled with LNG. Carrying LNG in partially filled tanks could lead to sloshing - a violent motion of the fluid. Sloshing could lead to an increased high pressure of LNG on the tank walls, especially in an abnormally harsh wave environment.[8] Bureau Veritas and other classification societies have filling limitations for LNG cargo systems (see Table 3 below).

Table 3. Limitations for LNG cargo systems

System	Filling Limitation
Membrane	FL between 10%L-70/80%H not allowed
MOSS	Without limits due to spherical geometry
IHI-SPB	Possibility to arrange wash bulkheads
FL: filling level, L: length of the tank, H: height of the tank.	
Source: Adapted from L. Delorme, A. Souto Iglesias and S. Abril Perez, "Sloshing Loads Simulation In LNG Tankers With SPH". International Conference On Computational Methods In Marine Engineering, MARINE 2005	

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[6] Welker J. R. and Sliepcevich C.M., Radiation, Heat Flux, and Overpressure in LNG Tanks, Proceedings of the International Conference on LNG Importation and Terminal Safety, Boston (1972).
[7] Hashemi H.T., West H. H. and Sliepcevich C.M., LNG/Water Explosions: A Distributed Source, Proceedings of the 27th Annual Petroleum Mechanical Engineering Conference (1972).
[8] Mateusz Graczyk, Torgeir Moan, "A probabilistic assessment of design sloshing pressure time histories in LNG tanks". Ocean Engineering 35 (2008) 834–855.

Possible sloshing effect might require additional modifications to LNG cargo systems, especially taking into account increasing size of LNG carriers. Several engineering organizations, including Det Norske Veritas (DNV) and Norwegian Marine Technology Research Institute, have projects underway, researching this important safety issue.

Earthquakes and Terrorism. The unexpected risks of earthquakes and terrorism are discussed in Appendix 4: Risk Perception.

HOW IS A SAFE, SECURE LNG VALUE CHAIN ACHIEVED?

The LNG industry has operated worldwide for more than 40 years with very few safety incidents (see Appendix 5: Major LNG Incidents). In any major industry, there are certain hazards and risks associated with day-to-day operations, as well as definable risks and hazards associated with construction of facilities. This report does not deal with industrial workplace hazards or hazards associated with construction of major facilities. In the U.S. and elsewhere, policies and regulations at federal, state, and local levels of jurisdiction are in place to protect industrial workplace environments and construction sites and to minimize, and even eliminate, lost time due to accidents and injuries.

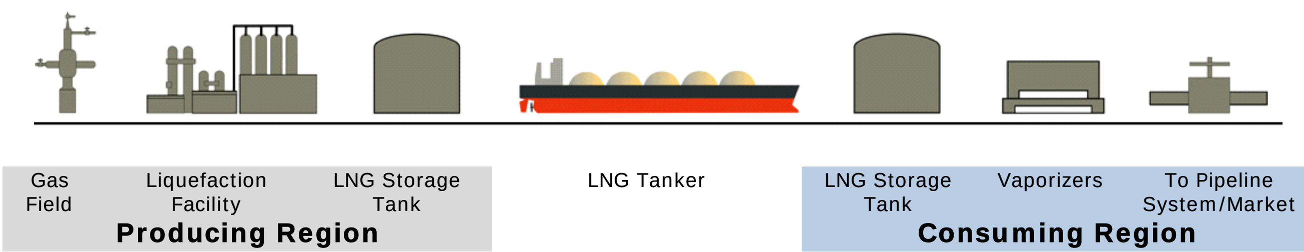
Our focus is on the properties of LNG, the particular hazards and risks that can develop from these properties and on the achievement of safety and security of LNG facilities. The major potential hazards of LNG and LNG vapors have been identified, analyzed, and taken into account, all to ensure the safe design, construction, operation, and maintenance and to prevent or mitigate the probability of these hazards. Prevention and mitigation steps are identified and implemented to reduce the probability of these hazards. Adherence to the regulations, codes, and operating practices makes the probability of an incident relating to such hazards extremely low. Much has been accomplished with respect to design and engineering of LNG facilities to address the risks and hazards associated with LNG. LNG facility design and engineering ensure that the experience is extended and safety record of the past 40 years continues into the future, so that society can reap the benefits of natural gas as a safe, clean fossil fuel.

Brief Overview of the LNG Value Chain

Our first briefing paper, ***Introduction to LNG***, provides details on the global LNG value chain. The major components of the value chain include the following (see Figure 5):

- *Natural gas production*, the process of finding and producing natural gas for delivery to a processing facility.
- *Liquefaction*, the conversion of natural gas into a liquid state so that it can be transported in ships.
- *Transportation*, the shipment of LNG in special purpose ships for delivery to markets.
- *Re-gasification*, conversion of the LNG back to the gaseous phase by passing the cryogenic liquid through *vaporizers*.
- *Distribution and delivery* of natural gas through the national natural *gas pipeline system* and distribution to end users.

Figure 5. LNG Value Chain



Source: CMS Energy

Storage is a major focus for safety and security. Once natural gas is liquefied, it is stored before shipment or loaded directly into the ship. LNG ships are required to have double hulls by regulation (International Maritime Organization) to facilitate safe transportation by sea. LNG receiving terminals and re-gasification facilities store LNG before it is re-gasified for pipeline transportation.

The LNG Value Chain in the U.S. and North America

The U.S. differs little from other countries that use LNG, with one significant exception: because LNG constitutes a relatively small proportion of the domestic natural gas supply base, LNG importation is not as familiar to the U.S. public as it is in other countries. In addition, while widespread use of LNG satellite storage and peak shaving facilities has been made by pipelines and natural gas utilities, the public is generally not aware of these facilities. A great deal of LNG industry activity has taken place in the U.S. and North America since 2000. For the most part, that activity has centered on development of new LNG import terminals. These new facilities have benefitted from the expertise gained elsewhere regarding state-of-the-art materials and technologies used to construct LNG storage tanks for onshore receiving terminals, ideas for offshore receiving and re-gasification facilities, and new ship designs. This experience will be of benefit should some import capacity be converted to export U.S. domestic natural gas production. Second, operating practices at both existing and new LNG import facilities reflect knowledge gained from experience. Third, our regulatory framework benefits from the new technologies, materials, and practices that are being shared worldwide. Fourth, public education is critical for LNG and its properties to be better understood as use of LNG for end user needs like truck transportation rapidly grows.

Most LNG facilities in the U.S. are peak shaving liquefaction and storage facilities, satellite storage facilities or marine import terminals. Only one facility in the U.S. is a baseload liquefaction facility, the Kenai, Alaska liquefaction and export terminal.

Figure 6. LNG Liquefaction Export Facility in Kenai, Alaska

Source: ConocoPhillips

Baseload LNG liquefaction export facilities around the world take a natural gas feed and pre-treat and refrigerate it until it becomes a liquid that can be stored at atmospheric pressure. These large processing facilities, consisting of one or more *LNG trains*, include gas treatment facilities, liquefaction systems, storage tanks, and LNG transfer terminals. The LNG liquefaction export facility located in Kenai, Alaska (as shown in Figure 6 above) currently is the only baseload liquefaction export facility in the U.S. LNG is exported to Japan; the Kenai to Tokyo Harbor route constituted the first Pacific Basin LNG trade route (see ***Introduction to LNG***). With new abundance in domestic natural gas supplies, additional liquefaction export facilities are contemplated for the Lower 48 States and western Canada. Terminals that have capacity to both import and export conceivably could help balance the U.S. and North American natural gas marketplace. Currently, LNG imports remain an important component of the U.S. natural gas supply portfolio, especially for seasonal natural gas needs in locations like New England. U.S. and North American import terminals receive LNG from baseload liquefaction facilities in other countries. Natural gas from Canada could be sent to Lower 48 markets; natural gas from U.S. domestic production, including Alaska, could be shipped to U.S. receiving locations.[9]

Peak shaving LNG facilities, as shown in Figure 7 below, liquefy and store natural gas produced during summer months for re-gasification and distribution during the periods of high demand, usually on cold, winter days. Peak shaving facilities use the same liquefaction processes as large baseload LNG facilities, but at a much smaller scale. In the case of peak shaving facilities, the natural gas feed is taken from the domestic pipeline system. In the U.S., local distribution companies (LDCs) have used LNG for peak shaving during high demand periods for more than 60 years. LNG peak shavers have provided secure and reliable supplies of natural gas for use during periods of peak demand.[10]

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[9] Section 27 (Jones Act) of the Merchant Marine Act of 1920 requires that all goods shipped in U.S. coastal waters between U.S. ports use U.S. flagged ships, constructed (or re-built) in the U.S., with U.S. ownership and maintenance and U.S. crews (citizens and permanent residents). Various attempts have been made to reform the Jones Act. The law was re-codified in 2006. See http://www.marad.dot.gov/documents/CabotageLaws.pdf and http://www.trans-inst.org/jones-act.html.

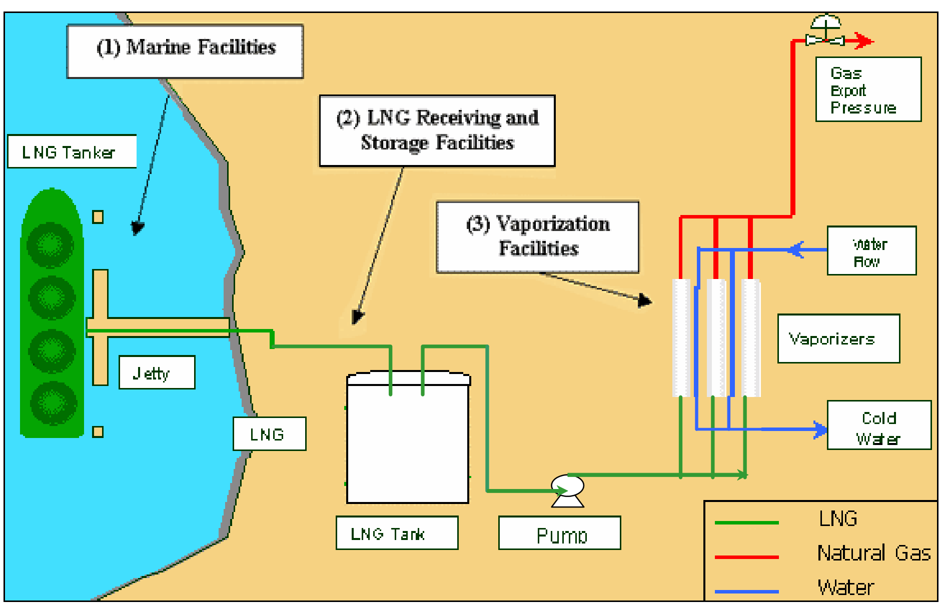
[10] Cates, Rusty, International Gas Consulting, Inc., "LNG - *Hedging Your Bets*," LNG: Economics & Technology Conference, January, 2003.

Figure 7. A Peak Shaving Facility

Source: CH·IV International

Perhaps most visible type of LNG facilities is *baseload LNG receiving and re-gasification facilities*. These facilities consist of marine terminals for LNG ships (1), LNG receiving and storage facilities (2), and vaporizing facilities and supporting utilities (3). Figure 8 provides a layout for typical onshore LNG baseload receiving facilities.

Figure 8. Typical LNG Receiving Terminal / Re-gasification Facility



Source: BP LNG. Note that type of vaporization process and related water requirements may vary. See Appendix 1: Descriptions of LNG Facilities for details.

Our first paper, ***Introduction to LNG***, provides information on LNG facilities in the U.S. and North America. Onshore LNG terminals are reviewed and certified by the U.S. Federal Energy Regulatory Commission (FERC). For information on the FERC review process and facilities see http://www.ferc.gov/industries/gas/indus-act/lng/exist-term.asp and http://www.ferc.gov/industries/gas/indus-act/lng/LNG-existing.pdf. The FERC also has authority to certify any LNG export facilities.

The majority of LNG import terminals are based onshore. In April 2005 Gulf Gateway Energy Bridge Deepwater Port[11] (see Figure 9 below) was put into operation as the world's first offshore liquefied natural gas (LNG) receiving facility and the first new LNG regasification facility in North America since 1980's. Gulf Gateway was followed by Neptune and Northeast Gateway, both serving New England.

Figure 9. The Energy Bridge™ System[12]

The Energy Bridge™ System is based on specially designed Energy Bridge™ Regasification Vessels (EBRV). These are equipped with shipboard regasification equipment and are capable of docking with a submerged offloading buoy anchored offshore. When an EBRV reaches the buoy, it is retrieved and locked into a specially designed compartment within the ship. Once attached, the buoy serves as both the mooring system for the vessel and as the offloading mechanism for transferring the vaporous natural gas to the downstream pipeline.

After connecting to the STL Buoy, LNG is brought up to the required pipeline pressure through onboard high-pressure pumps, and passed through a set of vaporizers,

[11] Find out more about offshore projects in the CEE publication "*LNG Offshore Receiving Terminals*".
[12] See http://www.excelerateenergy.com/offshore-regasification-gateway

which turn the LNG back into vaporous natural gas. Natural gas is then discharged through the buoy into a flexible riser, through a subsea manifold and into a subsea pipeline for ultimate delivery to onshore markets. Following regasification and cargo discharge, the buoy is released, re-submerging until it achieves neutral buoyancy at a depth of well below the surface of the water.

One of the major benefits of an offshore facility is "that it can contribute to the availability of natural gas supplies in a secure manner with minimal disturbance to the environment".[13] The U.S. Department of Transportation-Maritime Administration (MARAD) reviews and certifies offshore facilities. For information on the operating facilities mentioned above, as well as on the MARAD certification process, see http://www.marad.dot.gov/ports_landing_page/deepwater_port_licensing/dwp_current_ports/dwp_current_ports.htm. Like FERC, MARAD would certify any LNG export facilities that are based offshore. Both FERC and MARAD coordinate with all relevant federal, state, and local jurisdictions, agencies, and organizations that have some authority over LNG import and export facilities. The U.S. Department of Energy issues certificates for the import and/or export of natural gas. For details on regulatory oversight of LNG in the U.S. see Appendix 3: Who Regulates LNG in the U.S.?

When it comes to increasing supplies of natural gas beyond the critical base of domestic production, the key components are baseload receiving terminals and re-gasification facilities, and liquefaction facilities at the international supply source. The critical link between these two components of the LNG value chain is *shipping*. According to Maritime Business Strategies, there were 360 existing *LNG ships*, as of October 2011, with 47 on order.[14] Twenty three LNG ships were delivered in 2010, and orders for eighteen more were placed in the third quarter of 2011 alone. About 55 percent of the fleet is less than five years old. New LNG ships are designed to transport over 200,000 cubic meters (m^3) of LNG,[15] or about 2.8-3.1 billion standard cubic feet of natural gas. Various ship yards have begun designing larger

[13] "Energy Bridge Gulf of Mexico - Application for Issuance of a License to Construct and Operate a Natural Gas Deepwater Port", 2002.
[14] Maritime Business Strategies, LLC: http://www.coltoncompany.com/.
[15] Typically, LNG ship size is designated by cubic meters of liquid capacity. See Appendix 7: Conversion Table.

LNG ships with a capacity greater than 200,000 cubic meters (m^3), and thirteen ships of 263,000 m^3 and 270,000 m^3 capacity of LNG have been ordered already. The use of larger ships, which enable LNG value chain economics to improve and facilitate a larger supply base for the U.S. and other importing countries, is critical in determining how new baseload receiving terminals are designed as well as how existing facilities will be expanded. A typical ship measures some 900 feet in length, about 150 feet in width and has a 38-foot draft. LNG ships can be less polluting than other shipping vessels because they can burn natural gas, but may also substitute or supplement with fuel oil as an additional source for propulsion.

In the U.S., our LNG systems include a large number of smaller *satellite* storage facilities (shown in Figure 10) that allow natural gas to be located near areas of high demand and stored until the gas is needed. These facilities must also be operated safely and securely. Satellite LNG facilities have only storage and re-gasification equipment, but no liquefaction units. Some of these units perform satellite peak shaving duties, while others are dedicated to *vehicle fuel transfer* systems. LNG is usually delivered from marine terminals or peak shaving facilities to the satellite facilities by truck (shown in Figure 10, right). As interest in LNG for domestic fuel for trucks, railroads, and marine vessels grows, the need for satellite storage facilities also will increase.

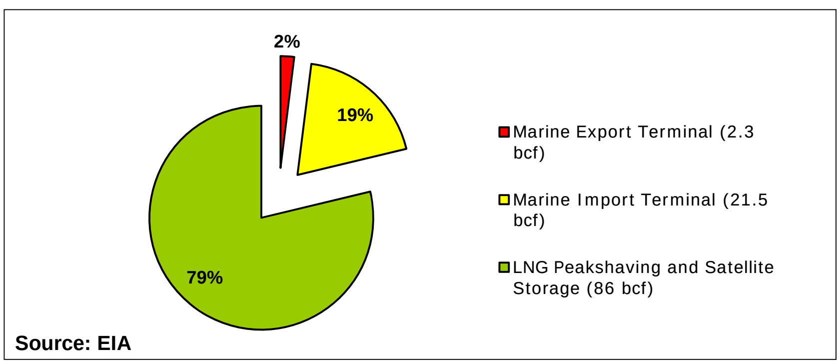
Figure 10. A Satellite Storage Facility (left) and LNG Truck (right)

Source: CH·IV International

Source: CH·IV International

There are about 260 LNG facilities worldwide. The U.S. has the largest number of those with about 121 active facilities. Natural gas is liquefied and stored at about 58 facilities in 25 states, including 96 connected to the U.S. natural gas pipeline grid. Massachusetts alone accounts for 14 major satellite facilities, or roughly 40 percent of all satellite facilities in the United States. New Jersey has five satellite LNG facilities, the second highest in the U.S. A rough summary of the types of LNG storage capacity in the U.S. is shown in Figure 11. According to the U.S. Energy Information Administration (EIA),[16] the estimated total storage capacity of LNG peak shaving and satellite facilities in the Lower 48 States as of mid-2004 is 86 billion cubic feet (BCF). LNG peak shaving and satellite storage account for 79 percent of U.S. LNG storage capacity, but it is only two percent of the total natural gas storage capability in the Lower 48. For example, in addition to LNG peak shaving and storage, domestic natural gas production is stored in underground caverns or depleted natural gas fields, which together account for the overwhelming proportion of natural gas storage capacity.

Figure 11. U.S. LNG Facilities Storage Capacity



Despite the relatively low percentage of total gas storage capacity represented, the high daily deliverability of LNG facilities makes them an important source of fuel during winter cold snaps. LNG facilities can deliver up to about 11 BCFD (BCF per day), or the equivalent of 14 percent of the quantity of gas supply that can be delivered from underground storage locations in the U.S.

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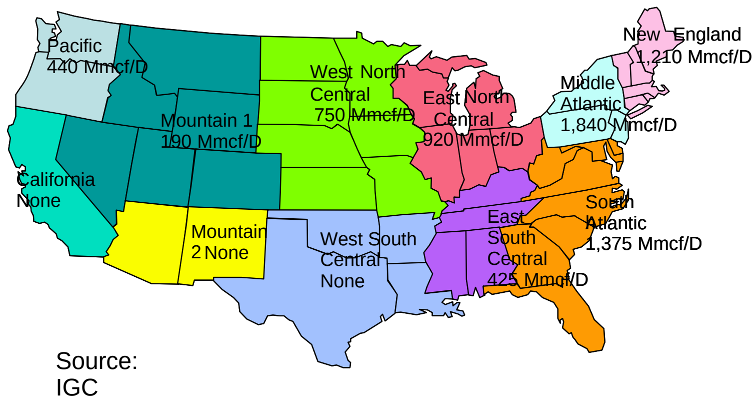
[16] U.S. EIA: U.S. LNG Markets and Uses: June 2004 Update.

Figure 12. U.S. Regional LNG Storage Deliverability



Application of Safety Conditions to the LNG Value Chain

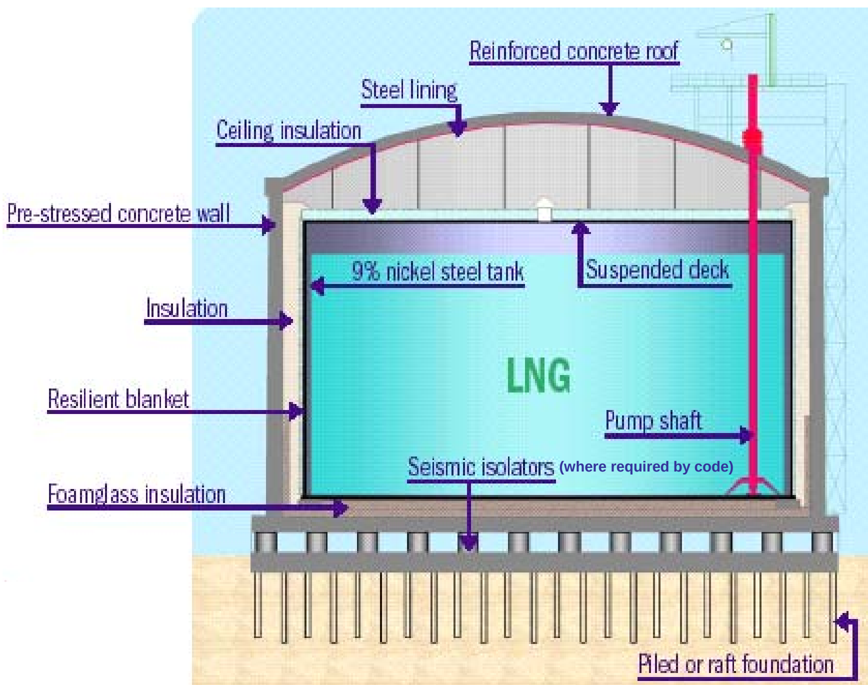
In this paper, we do not address risks and hazards associated with exploration and production activities, processing of natural gas or safety and security associated with natural gas pipeline or local gas utility distribution systems. The U.S. and other countries maintain health, safety, and environment (HSE) policies and regulations that apply to all of these activities and sites as well as specialized policies, regulations, and industry standards targeted to specific needs and hazards. Worldwide, best practices for all of these activities have evolved and are becoming more firmly embedded in contractual and regulatory frameworks that establish the safety conditions of industry operations. The specific safety and security features embedded in the LNG value chain, as they pertain to the four elements of primary containment, secondary containment, safeguard systems and separation distances, are detailed below, following our schematic in Figure 2 of the multiple layers of protection.

PRIMARY CONTAINMENT

International standards and rules define containment with respect to types of structures and technologies in use. We use the term “containment” in this document to mean safe storage and isolation of LNG. Safe use of LNG, or any cryogenic substance, requires an understanding of how materials behave at cryogenic temperatures. For example, at extremely low temperatures, carbon steel loses its ductility and becomes brittle. The material selected for tanks, piping, and other equipment that comes in contact with LNG is critical. The use of high nickel content steels, aluminum, and stainless steels is costly but necessary to prevent embrittlement and material failures. High alloy steels composed of nine percent nickel and stainless steel typically are used for the inner tank of LNG storage tanks and for other LNG applications.

Several engineering design features ensure the safety of LNG storage tanks (see Figure 13 below). LNG typically is stored in double-walled tanks at atmospheric pressure. The storage tank is a tank within a tank, with insulation between the walls of the tanks.

Figure 13. Conceptual Design of Storage Tanks



Source: Shell

In single containment tanks, the outer tank is generally made of carbon steel. It provides no protection in the event of the failure of the inner tank, but holds the insulation in place. The inner tank, in contact with the LNG liquid, is made of materials suitable for cryogenic service. It has a flat metallic bottom and a cylindrical metal wall both built of materials suitable for cryogenic temperatures (usually nine percent nickel steel). Pre-stressed concrete and aluminum have also been used for inner tanks. The inner tank bottom rests on a rigid insulation material, such as foam glass. The strength of the total tank must withstand the hydrostatic load of the LNG. This hydrostatic head determines the thickness of the inner tank side walls. The tanks also have an insulation layer with a flat suspended deck supported by an outside domed roof vapor barrier or outer tank (often made of carbon steel). All new tank piping designs are through the roof of the tank to avoid siphoning of the full content of the tank in case of piping failures.

A *single containment* tank (shown in Figure 14 below) for LNG is a tank system comprised of an inner tank and an outer container. The engineering design requires only the inner tank to meet the low temperature ductility requirements for storage of the product. The outer container of a single containment storage tank serves primarily to retain insulation and vapor. It is not designed to contain LNG due to leakage from the inner tank. Storage tanks may also use double or full containment designs as described in the following section on Secondary Containment. In double or full containment, the outer tank is designed to contain the full amount of the inner tank in case of a failure of the inner tank.

Figure 14. Single Containment Tanks

Source: Williams

Engineering design for safety also applies to LNG ships. An onboard containment system stores the LNG, where it is kept at atmospheric pressure (to keep air from entering the tank) and at -256°F (-160°C). Existing LNG ship cargo containment systems reflect one of three designs. As of October 2011:

- Spherical (Moss) design accounts for 30 percent of the existing ships,
- Membrane design account for about 68 percent, and
- Self-supporting structural prismatic design account for about 2 percent.

Ships with spherical tanks are most readily identifiable as LNG ships because the tank covers are visible above the deck (see Figure 15).

Figure 15. A Spherical Tank

Source: CMS

Many ships currently under construction, however, are membrane type ships. *The membrane and prismatic ships* look more like oil tankers with a less visible containment tank structure above the main deck. The cargo containment systems of membrane-type LNG ships (see Figure 16) are made up of a primary container, a secondary containment, and further insulation.

Figure 16. LNG Lagos - Membrane Type LNG Carrier

Source: NLNG

The *primary container* is the primary containment for the cargo. It can be constructed of stainless steel, invar (36 percent nickel steel). The most common cargo *insulation* materials include polyurethane, polyvinyl chloride foam, polystyrene, and perlite. Nitrogen is placed in the insulation space. Because nitrogen does not react with other gases or materials, even minor leaks can be detected by monitoring the nitrogen-filled insulation space for the presence of methane.

SECONDARY CONTAINMENT

Secondary containment provides protection beyond the primary containment. This applies both to storage tanks at receiving/re-gasification terminals as well as LNG ships. A *dike, berm, or dam impoundment* usually surrounds a single containment tank located onshore in order to contain any leakage in the unlikely event of tank failure. This system allows any released LNG to be isolated and controlled. The dikes are designed to contain 100 percent to 110 percent of tank volume and to be high enough so that the trajectory of a leak at the upper liquid level in the tank will not overshoot the edge of the dike. Most of the existing LNG tanks at U.S. peak shaving facilities and marine import facilities are single containment with secondary containment provided via impoundments. Single containment tanks require larger land areas for LNG storage facilities because of the larger potential spill area of the dike impoundment.

A *double containment* tank (illustrated in Figure 17) is designed and constructed so that both the inner tank and the outer tank are capable of independently containing the refrigerated liquid. The inner tank contains the LNG under normal operating conditions. The outer tank or wall is intended to contain any LNG leakage from the inner tank and the boil-off gas. The majority of LNG storage tanks built recently around the world is designed as double or full containment tanks.

Figure 17. Double Containment Tanks

Source: ALNG

Similar to a double containment tank, a *full containment* tank is designed and constructed so that both the inner tank and the outer tank are capable of independently containing the stored LNG. The inner tank contains the LNG under standard operating conditions. The outer tank or wall composed of approximately three feet of concrete is one to two meters away from the inner tank. The outer tank supports the outer roof and is intended to contain the LNG.[17] The tanks are designed in accordance with international LNG codes (EMMUA 147,[18] EN 1473). The full containment tank is less susceptible to damage from external forces. Full containment LNG tanks, with reinforced concrete walls and roofs can be found in Japan, Korea, Greece, Turkey, Portugal (see Figure 18). Cameron LNG, LLC has recently built a full containment LNG tank system for the new LNG terminal in Hackberry, Louisiana.

[17] All protocols on tank design and safety based on British Standards Institution (BSI) BS 7777: 1993 Parts 1. See http://www.hse.gov.uk/comah/sragtech/docsbsi.htm.
[18] U.K. Engineering Equipment and Materials Users Association (EEMUA), 1986, http://www.hse.gov.uk/comah/sragtech/techmeasplant.htm.

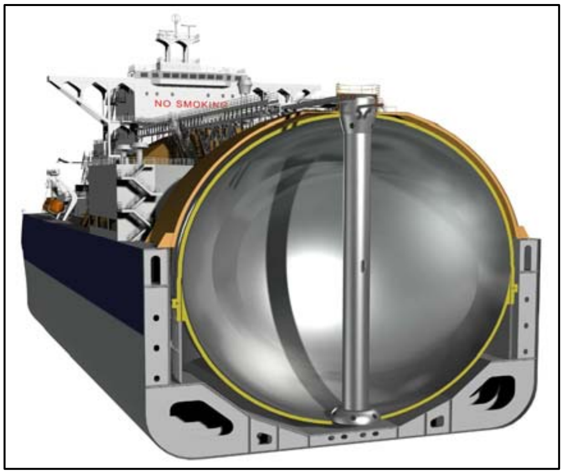
Figure 18. Full Containment Tanks

Source: CH·IV International

The safety records of the onshore LNG facilities around the world demonstrate that the primary containment of the LNG tanks is safe, because *secondary spill containment* systems installed around all of the tanks, have never been required to hold liquid. LNG operators also are required to provide containment and design of troughs to direct the flow of LNG to a drain sump in a safe location in those process areas where an LNG spill could occur, such as in transfer piping or LNG truck loading areas and vaporization units.

For LNG ships, regulations concerning a *secondary barrier* depend on the type of construction of the storage tanks. It may be a complete secondary containment mechanism for membrane design ships that is equivalent to the primary barrier. In the case of ships with independent tanks, such as the spherical and structural prismatic design systems, the secondary barrier is a *splash barrier* with a *drip pan* at the bottom from which accumulated liquid evaporates (see Figure 19). Materials used to construct the secondary barrier include aluminum or stainless steel foil, stainless steel and invar.

Figure 19. Tank Section of a Spherical Moss Design



SAFEGUARD SYSTEMS

All LNG facilities are designed to comply with spill containment requirements. They have extensive safety systems to *detect LNG releases* using a number of gas detectors (for methane), ultraviolet or infrared fire detectors, smoke or combustion product detectors, low temperature detectors and detectors to monitor LNG levels and vapor pressures. Closed-circuit television systems monitor all critical locations of LNG facilities. Emergency shutdown systems can be activated upon detection of leaks, spills, or gas vapors. While there are different types of designs for LNG facilities HSE considerations are generally similar. Various codes and standards (see later section on Industry Standards/Regulatory Compliance) ensure that the chances of a release are minimal, as is its volume if a release occurs.

LNG transfer lines are designed to prevent releases. Should there be a failure of a segment of piping at an LNG facility, a spill of LNG or leak of gas vapor could occur. An LNG spill from a transfer line is very unlikely due to the design requirements for equipment, such as use of proper materials of construction, minimal use of bolted flanges and rigorous testing of LNG piping. Gas and fire detectors throughout the facility activate alarms and foam systems to ensure rapid dispersion or containment of gas vapors and any fire hazard.

Fire detection sensors at LNG facilities would sound an alarm and immediately begin a shutdown procedure. Foam, dry chemical, and/or water would be dispersed immediately from automated *firefighting systems*. If there is an ignition source, then a *pool fire* would develop at the liquid LNG release point. LNG vapor burns with very little smoke. The LNG quickly evaporates due to the heat of the surroundings and the flame. If a release of LNG goes unignited for a period of time, then a vapor cloud can form. If ignited, a vapor cloud burns back to the source of the release. The speed of burn depends on conditions such as the size of the release and weather conditions.

LNG ships are designed with a *double hull*. This design provides optimum protection for the integrity of the cargo in the event of collision or grounding as well as separate ballast. Separate from the hull design, LNG ships have *safety equipment* to facilitate ship handling and cargo system handling. The ship-handling safety features include sophisticated radar and positioning systems that enable the crew to monitor the ship's position, traffic and identified hazards around the ship. A global maritime distress system automatically transmits signals if there is an onboard emergency requiring external assistance. The cargo-system safety features include an extensive instrumentation package that safely shuts down the system if it starts to operate outside of predetermined parameters. Ships also have gas and fire detection systems, and nitrogen purging. Should fire occur on a ship, two 100 percent safety relief valves are designed to release the ensuing boil off to the atmosphere without over-pressurizing the tank.

LNG ships use approach velocity meters when berthing to ensure that the prescribed impact velocity for the berth fenders are not exceeded. When moored, automatic mooring line monitoring provides individual line loads to help maintain the security of the mooring arrangement while alongside. When connected to the onshore system, the instrument systems and the shore-ship LNG transfer system acts as one system, allowing emergency shutdowns of the entire system from ship and from shore.

LNG ships and facilities have redundant safety systems, for example, Emergency Shutdown systems (ESD). A redundant safety system shuts down unloading operations when the ship or unloading facility is not performing within the design parameters.

SEPARATION DISTANCE

In the U.S., regulators regulate *setbacks or protection distances* for LNG storage and other facilities. The federal safety standards on LNG facilities are found in the U.S. Code of Federal Regulations (CFR) 49, Part 193.[19] Setbacks are important for protecting surrounding areas should the unlikely release of LNG or a fire occur at an LNG facility. The regulations specify that each LNG container and LNG transfer systems have a *thermal radiation protection zone* beyond the impoundment area.[20] Each onshore LNG container or tank must be within a secondary dike or impoundment area. These thermal radiation exclusion zones must be large enough so that the heat from an LNG fire does not exceed a specified limit for people and property. The thermal radiation exclusion zone must be owned or controlled by the operator of the LNG facility. The code also specifies how the thermal radiation distance is calculated for each LNG facility. The Gas Technology Institute (GTI) computer model or a similar model is to be used and wind speed, ambient temperature and relative humidity producing the maximum exclusion distances are to be applied subject to other detailed provision of the regulation.

Similar to the provision for thermal radiation protection, the U.S. federal regulation 49 CFR Part 193 specifies that each LNG container and LNG transfer system must have a *flammable vapor dispersion exclusion zone* around the facility that is owned or controlled by the facility operator. The vapor dispersion exclusion zone must be large enough to encompass that part of the vapor cloud which could be flammable. The code specifies how the flammable vapor dispersion distance is calculated for each LNG facility. In order to account for irregular mixing of the vapor cloud, the regulation designates the vapor cloud hazard area as the area where the average gas concentration in air is equal to or greater than 2.5 percent (half of the lower flammability limit of methane). This provides a margin of safety to account for irregular mixing. The regulation also specifies other parameters including

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[19] 49 CFR Part 193: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div5&view=text&node=49:3.1.1.1.9&idno=49.

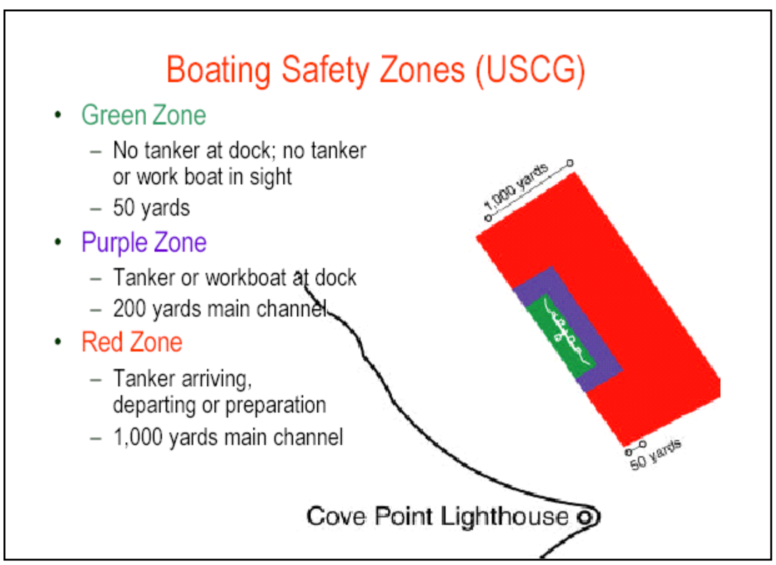
[20] The term *impoundment* is used in the LNG industry to identify a spill control design that will direct and contain the liquid in case of a release. Earthen or concrete dikes may provide impoundment surrounding an LNG container.

dispersion conditions that should be used in computing the dispersion distances. Computer models are used to calculate dispersion distances. Under U.S. regulations, protection distances are to be calculated specific to each location to prevent exposure to fire or thermal radiation.

Safety zones differ for ships in transit as opposed to ships in port. Port safety zones are established by the USCG and port captain, based on the specific risk factors at a given terminal. There are two purposes for safety zones for LNG ships – to minimize collision while the ship is underway, and at berth to protect surrounding property and personnel from hazards that could be associated with ignition. In the U.S., the use of safety zones around LNG ships began in 1971 at the Everett Terminal in Boston Harbor. Safety zones are established based on the specific circumstances, including navigational requirements, in a specific area.

In some ports, the USCG may require a tug escort and specified safety zones around LNG ships when a ship is underway to a U.S. receiving terminal. The USCG's intention is to minimize disruption to area shipping and boating traffic while ensuring safe operations. Tugs assist in the safe docking of LNG ships. Figure 20 shows an example of a safety zone around the LNG tanker at Cove Point LNG terminal.

Figure 20. Example Safety Zone: Cove Point



Source: Williams

INDUSTRY STANDARDS/REGULATORY COMPLIANCE

In the U.S., several *regulatory authorities* govern the LNG industry. The U.S. Department of Energy–Office of Fossil Energy[21] helps to coordinate across federal agencies that have regulatory and policy authority for LNG. The U.S. Federal Energy Regulatory Commission (FERC)[22] is responsible for permitting new onshore LNG receiving terminals in the U.S. and ensuring safety at these facilities through inspections and other forms of oversight. The USCG is responsible for assuring the safety of all marine operations at LNG receiving terminals and for LNG ships in U.S. waters.

The Deep Water Ports Act (DWPA) gives the USCG jurisdiction over permitting of offshore LNG receiving terminals in federal waters and for all marine operations for an offshore receiving terminal used as a deep water port.[23] The U.S. Department of Transportation (DOT)[24] regulates offshore receiving terminals and operations.

The U.S. Environmental Protection Agency (EPA)[25] and state environmental agencies establish air and water standards for the LNG industry. Other U.S. federal agencies involved in environmental and safety protection include the Fish and Wildlife Service,[26] Army Corps of Engineers[27] (for coastal facilities and wetlands), Bureau of Ocean Energy Management, Regulation, and Enforcement[28] (for offshore activities), National Oceanic and Atmospheric Administration[29] (for any activities near marine sanctuaries), and Department of Labor Occupational Safety & Health Administration (OSHA)[30] for LNG workplace protections. These agencies, as well as DOT, USCG, and FERC, all have authority over comparable activities for industries other than LNG.

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[21] U.S. Department of Energy – Office of Fossil Energy: http://www.fe.doe.gov/.
[22] U.S. Federal Energy Regulatory Commission (FERC): http://www.ferc.gov.
[23] U.S. Coast Guard (USCG): http://www.uscg.mil/.
[24] U.S. Department of Transportation (DOT): http://www.dot.gov/.
[25] U.S. Environmental Protection Agency (EPA): http://www.epa.gov/.
[26] U.S. Fish and Wildlife Service: http://www.fws.gov/.
[27] U.S. Army Corps of Engineers: http://www.usace.army.mil/.
[28] U.S. Bureau of Ocean Energy Management, Regulation, and Enforcement: http://www.boemre.gov/.
[29] U.S. National Oceanic and Atmospheric Administration: http://www.noaa.gov/.
[30] U.S. Department of Labor Occupational Safety & Health Administration (OSHA): http://www.osha.gov

State, county and local (municipal) agencies also play roles to ensure safe and environmentally sound construction and operation of LNG industry facilities. Local agencies also provide support for emergency response that might be needed beyond what an LNG facility might provide. Appendix 3: Who Regulates LNG in the U.S.? includes more detail the role of regulatory authorities with respect to the LNG industry.

Federal, state and local jurisdictions impose and enforce numerous *codes, rules, regulations, and environmental standards* on LNG facilities. These are designed to prevent or minimize the impact of a leak or spill by minimizing the quantity spilled, containing any spill, and erecting barriers between potential spills and adjacent areas. In short, they *both reflect and establish* the four conditions for LNG safety and security.

With industry interaction and in light of international industry best practices, the industry also creates its own codes, rules, regulations and environmental standards. In this way, policies and regulation for LNG safety and security can reflect state-of-the-art technologies and operational practices based on performance history and extensive research and development, design, and testing. In the U.S., federal regulations are provided in the Code of Federal Regulations (CFR).[31] The following regulations and standards/codes provide guidelines for the design, construction and operation of LNG facilities. See Appendix 2: LNG Regulations for details.

- 49CFR Part 193 *Liquefied Natural Gas Facilities: Federal Safety Standards*
- 33CFR Part 127 *Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas*
- NFPA 59A[32] *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*
- NFPA 57 *Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems*
- API 620 *Design and Construction of Large, Welded Low Pressure Storage Tanks*

[31] U.S. Code of Federal Regulations: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=%2Findex.tpl.
[32] The National Fire Protection Association (NFPA): http://www.nfpa.org/. The NFPA began developing NFPA 59A in 1960 by a committee of the American Gas Association and was adopted in 1967.

The worldwide LNG value chain could not develop without the evolution of international standards that can apply to LNG operations wherever they are located. Because LNG use has grown faster outside of the U.S. than it has domestically over the past several years, much research and development, design, and testing activity has occurred in other countries. Countries that rely extensively on LNG to meet their energy needs – such as Japan, South Korea, and some European nations – or countries that have extensive LNG production like Australia have had to make considerable investment in policies and regulations that support a safe and secure LNG industry. European standards include the following.

- EN 1473 - The European Norm standard EN 1473 *Installation and equipment for Liquefied Natural Gas - Design of onshore installations* evolved out of the British Standard, BS 7777[33] in 1996.
- EN 1160 – *Installation and equipment for Liquefied Natural Gas – General Characteristics of Liquefied Natural Gas*.
- EEMUA 147[34] - *Recommendations for the design and construction of refrigerated liquefied gas storage tanks*.

International rules and norms also provide oversight for LNG ships. In addition, within the U.S., the USCG and other agencies enforce a number of regulations available to protect ships and the public. Some of these apply to shipping operations other than LNG ships. (The USCG has long experience with shipping operations for a myriad of energy fuels, chemicals, and other materials, all of which pose a variety of potential risks and hazards, as does recreational boating.)

- 33 CFR 160.101 *Ports and Waterways Safety: Control of Vessel and Facility Operations*.
- 33 CFR 165.20 *Regulated Navigation Areas and Limited Access Areas: Safety zones*.
- 33 CFR 165.30 *Regulated Navigation Areas and Limited Access Area: Security Zones*.

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[33] British Standards Institution (BSI) BS 7777. See footnote 17.
[34] See footnote 17.

With regard to *environmental standards*, all LNG facilities must meet applicable regulations for air, water, and other health and ambient environmental protections. Proposals for new LNG facilities must incorporate environmental assessments to determine overall impact of the facility and its operation.

Before LNG projects are implemented, studies must be carried out, including:

- assessments of siting requirements;
- baseline biological and land use surveys and impact analyses;
- facility process design;
- evaluations of the operational constraints and hazards associated with the facility, terminal facilities, and shipping of LNG including earthquake tolerance;
- compatibility of LNG facilities with current and projected uses of waterways and adjacent lands;
- assessment of potential risks to the public near prospective sites; and
- Assessment of potential effects of facility construction and operation on terrestrial and aquatic ecosystems.

The studies involve analyses of oceanographic, navigational, and meteorological conditions to determine whether access by LNG ships is feasible and safe, and whether operation of existing facilities along the waterways would be affected.

A new LNG facility would be considered a potential new source of air pollution and would require approval of a regulatory agency responsible for monitoring air quality. Upon receipt of approval, the project would be monitored for compliance with all quality rules, regulations and standards. The impact of new emissions on air quality, if any, would be compared to existing air quality levels.

Air emissions that result from combustion of vaporized LNG as a fuel, for example in vehicles or vaporizers or for electric power generation, represent the primary environmental impacts associated with increased LNG use. Demand for LNG reflects a demand for natural gas. Compared to other fossil fuels, natural gas generally has lower emissions of carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (VOC), and fine particulates (less than

2.5 microns in size). In addition, natural gas has lower emissions of carbon dioxide (CO_2) and toxic, heavy metals.[35] Since the liquefaction process requires removal of all impurities from the produced natural gas, LNG actually has *lower* air emissions than natural gas when it is produced. The sulfur content of LNG is near zero, eliminating sulfur dioxide (SO_2) emissions.

There are secondary sources of emissions associated with power facilities on site (which must have separate permits), LNG ships, and other marine vessels (e.g., diesel dredgers, USCG security vessels, and tugs). The diesel and bunker fuels used to operate the vessels cause most emissions from marine vessels.

LNG is a source of environmental benefits. When natural gas is burned for power generation SO_2 emissions are virtually eliminated and CO_2 emissions are reduced significantly compared to other fuels such as coal and fuel oil, which require scrubbing or other technologies to remove SO_2 or carbon reduction strategies such as sequestration to deal with CO_2.

In some crude oil producing countries like Nigeria, where there are few alternatives for use or disposal of the natural gas that is produced with crude oil, some of the gas that would otherwise be flared is instead converted to LNG. This reduces the environmental impact of the continuous flaring of large quantities of natural gas. To end flaring is a goal for the producing industry and institutions like the World Bank. These initiatives have contributed to the increased interest in LNG as a means of using valuable natural gas resources and contributing toward sustainable development.

Industry organizations help to coordinate interaction between the LNG industry, the agencies and authorities charged with creating and enforcing rules and regulations for LNG facilities. The *International Maritime Organization (IMO)* [36] has developed standards for the construction and operation of all ships. These standards and codes govern the design, construction and operation of specific ships, including LNG ships, and, when ratified, are adopted and incorporated into the individual flag state

[35] New York Energy Planning Board, *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.
[36] International Maritime Organization (IMO), http://www.imo.org.

regulations. In the U.S., the USCG has adopted the applicable IMO standards and codes in regulations covering U.S. flag ships. The USCG inspects LNG ships when in U.S. port, regardless of their flag state for compliance with these codes.

The Maritime Transportation Security Act of 2002 (MTSA) and the International Ship and Port Facility Security (ISPS) codes recommend additional security measures relating to ships and port facilities personnel and operational requirements. By July 1, 2004, as with other critical fuels and products, all LNG ships and terminals worldwide had to have specific security plans in place as required by the IMO and the USCG. The LNG ship Berger Boston (which is under long-term charter to Tractebel LNG North America) is the first vessel in the world to receive the new ISPS certification. The certification was received in June 2003.

Maritime Classification Societies provide the means by which LNG shipping operators can demonstrate that they have established clear, practical, technical standards that address the protection of life, property, and the natural environment.[37] The classification societies establish rules for the construction of LNG ships using IMO standards as a minimum. They can, on behalf of Flag States, certify existing proven technologies and methods of construction and have assisted in gaining approval for the development of new technologies so that they can be tested and then built. Some of the societies that classify LNG ships include American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV) and Lloyd's Register of Shipping (LR).

LNG regulations and industry standards complement each other. They apply to the design, construction, and operation of LNG facilities and have been developed by using best engineering practices and incorporating many years of operating experience.

CONCLUSIONS

As mentioned in our ***Introduction to LNG***, LNG has been handled safely for many years and the industry has maintained an enviable safety record. Engineering and

[37] Sember, W.J., ABS, Development of Guidelines for Classification of Offshore LNG Terminals, GASTECH 2002, Qatar, October 2002.

design and increasing security measures are constantly improved to ensure the safety and security of LNG facilities and ships.

As of 2011, the global LNG industry comprises 25 export (liquefaction) facilities, 91 receiving (re-gasification) terminals, and 360 ships, altogether handling more than 220 million metric tons of LNG every year. LNG has been safely delivered via ocean-going transport for more than 40 years. During that time there have been more than 59,000 LNG ship voyages, covering more than 110 million miles, without any major incidents involving a major release of LNG either in port or on the high seas. LNG ships frequently transit high traffic density areas. For example, in 2000, one LNG cargo entered Tokyo Bay every 20 hours, on average, and one LNG cargo a week entered Boston harbor.[38] Appendix 5: Major LNG Incidents provides extensive details on documented incidents in the LNG industry as well as background on some of the kinds of concerns, such as the impact of earthquakes on LNG facilities that the industry must protect against.

In the study by the New York Energy Planning Board of November 1998, carried out to inform the New York state governor and legislature on whether to extend or modify the 1978 moratorium on siting new LNG facilities, a major finding was: "Given its physical and chemical properties, LNG is as safe as other currently available fuels. Since 1980, there have been only seven facility or ocean tanker accidents worldwide and four vehicle related accidents in the United States, with no fatalities, which compares favorably with the safety record of facilities for competing fuels."[39] As a result of this report and review, in 1999 the moratorium was allowed to expire for areas outside of New York City.

Reviews such as the one conducted in New York in 1998 and the extensive body of information and evidence that documents LNG industry safety records and practices support our conclusion that risks and hazards associated with LNG and LNG industrial facilities are manageable. They also show that LNG industry safety practices contribute toward reduced potential for catastrophic events such as might

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[38] Phil Bainbridge, VP BP Global LNG, *LNG in North America and the Global Context,* IELE/AIPN Meeting University of Houston, October 2002.
[39] New York Energy Planning Board, *Report on issues regarding the existing New York Liquefied Natural Gas Moratorium*, November 1998.

be associated with acts of terrorism. Overall, LNG safety is inherent in the properties of LNG, the technologies and operating practices that have evolved on the basis of understanding these properties, and regulatory requirements.

Other publications of the *Center for Energy Economics* mentioned in this paper and the complete online *Guide to LNG in North America* provide extensive information to those interested in U.S. energy trends and security; LNG industry and market developments. The CEE web site, www.beg.utexas.edu/energyecon/lng provides links to industry, government and public information sources. Companies with LNG operations maintain active public information offices, as do the federal agencies charged with regulatory and policy oversight.

APPENDIX 1: DESCRIPTIONS OF LNG FACILITIES

Information in this appendix provides further information on the critical features of major LNG facilities as they relate to safety and security. A typical, onshore LNG receiving terminal and re-gasification facility, like those that currently exist in the U.S. and ones that are planned or proposed, consists of marine facilities, LNG receiving and storage facilities, and vaporization facilities.

Marine Facilities. The LNG dock facilities are designed to berth and unload LNG from ships. Tugboats provide assistance when berthing. The dock is designed to accept a specified size range of LNG ships.

LNG Receiving and Storage Facilities. Once the LNG ship is moored and the unloading arms on the dock have been connected, the ship's pumps will transfer LNG into the onshore LNG storage tanks. Offloading generally takes about 12 hours depending on cargo size. Figure 21 illustrates unloading arms at an LNG marine terminal. Double-walled tanks store LNG at atmospheric pressure. LNG is a cryogenic fluid, and it is not stored at high pressures, so an explosion of LNG from overpressure is not a potential hazard. The issues regarding LNG storage tanks apply both to the liquefaction and re-gasification facilities because the storage tanks are of the same design. New technologies enabled offshore LNG storage and re-gasification.

Figure 21. LNG Jetty with Unloading Arms - ALNG

Source: Phillips66

Offshore LNG receiving facilities. As noted previously, offshore facilities have already been developed and put into service. A variety of offshore options exists, and floating LNG facilities are gaining increasing interest to add value chain flexibility and commercialize remote natural gas resources. See CEE's review of offshore LNG as part of our online guide, ***LNG Offshore Receiving Terminals***, at http://www.beg.utexas.edu/energyecon/lng/LNG_OFFSHORE_RECEIVING_TERMINALS-release-updated.pdf.

Types of LNG Storage Tanks

Above-ground Tanks

Above-ground tanks have been the most widely accepted and used method of LNG storage primarily because they are less expensive to build and easier to maintain than in-ground tanks. There are more than 200 above-ground tanks worldwide, and they range in size from 45,000 barrels to 1,000,000 barrels (7,000 m^3 to 200,000m^{3}[40]). In Japan, Osaka Gas announced building one of the largest above-ground tank (230,000m^3), using new technologies for pre-stressed concrete design and enhanced safety features, as well as a technology for incorporating the protective dike within the storage tank (see description of full containment systems in section *Secondary Containment*).[41]

Below-ground Storage Tanks

Below-ground LNG tanks are more expensive than above-ground tanks. They harmonize with the surroundings. There are three different types of below-ground LNG storage tanks currently in use.

In-ground Storage Tanks

The roof of the tank is above ground. Japan has the world's largest LNG in-ground storage tank, which has been in operation since 1996. It has a capacity of 200,000 m^3. There are 61 in-ground storage tanks in Japan.

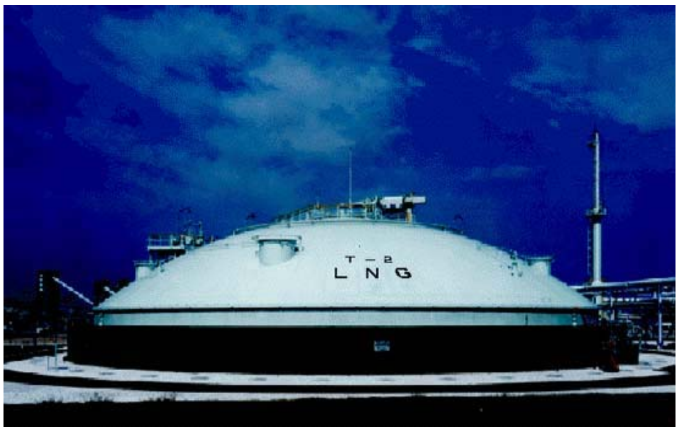
[40] Young-myung Yang et al. Development Of The World's Largest Above-Ground Full Containment LNG Storage Tank. 23rd World Gas Conference, Amsterdam 2006. Available at: http://www.igu.org/html/wgc2006/pdf/paper/add10896.pdf

[41] Osaka Gas to Build Large-Capacity LNG Tank at Senboku No.1 Works. Diamond Gas Report, September 13, 2011.

Underground LNG Storage Tank

Underground tanks (shown in Figure 23) are buried completely below ground and have concrete caps. This design not only minimizes risk, but the ground surface can then be landscaped to improve the aesthetics of the area.

Figure 22. Underground LNG tank: T-2 tank at Fukukita station of Saibu Gas Co., Ltd.



Source:

Underground In-pit LNG Storage Tank

The tank has a double metal shell with an inner and outer tank. The inner tank is made of metal with high resistance to low temperature. Additional insulation of thermal insulating materials and dry nitrogen gas fills the space between the inner and outer tanks. See Figure 25 for an example of an in pit LNG storage tank.

Figure 23. In pit LNG storage tank

Source: SIGTTO

LNG Vaporization Facilities

Each LNG storage tank has send-out pumps that will transfer the LNG to the vaporizers. Ambient air, seawater at roughly 59°F (15° C), or other media such as heated water, can be used to pass across the cold LNG (through heat exchangers) and vaporize it to a gas. The most commonly used types of vaporizers are the Open Rack (ORV) and the Submerged Combustion (SCV). Other types include Shell & Tube exchanger (STV), Double Tube Vaporizer (DTV), Plate Fin Vaporizer (PFV), and Air Fin Vaporizer (HAV).

Open Rack Vaporizer (ORV)

ORVs (shown in Figure 24) use seawater as the heat source. Seawater flows down on the outside surface of the aluminum or stainless steel heat exchanger panel and vaporizes LNG inside of the panel. Baseload operations use ORVs. Peak shaving operators use the same open rack vaporizers with circulating heated water. ORVs have the following special features:

- Simple construction and easy maintenance;
- High reliability and safety.

Figure 24. Open Rack Vaporizer

Source: www.spp.co.jp

Submerged Combustion Vaporizer (SCV)

SCVs use hot water heated by the submerged combustion burner to vaporize LNG in the stainless tube heat exchanger. SCVs (shown in Figure 25) are applied mainly to the vaporizer for emergency or peak shaving operation, but also can be used as a baseload. SCVs have the following special features:

- Low facility cost;
- Quick startup;
- Wide allowable load fluctuation.

Figure 25. Seven Submerged Combustion Vaporizers, Lake Charles, La., Terminal

Source: www.cmspanhandlecompanies.com

APPENDIX 2: LNG REGULATIONS

The following regulations provide guidelines for the design, construction and operation of LNG facilities.

- 49CFR Part 193 *Liquefied Natural Gas Facilities: Federal Safety Standards*- This section covers siting requirements, design, construction, equipment, operations, maintenance, personnel qualifications and training, fire protection, and security.

- 33CFR Part 127 *Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas* - This federal regulation governs import and export LNG facilities or other waterfront facilities handling LNG. Its jurisdiction runs from the unloading arms to the first valve outside the LNG tank.

- NFPA 59A *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)* – This is an industry standard issued by the National Fire Protection Association (NFPA).[42] NFPA 59A covers general LNG facility considerations, process systems, stationary LNG storage containers, vaporization facilities, piping systems and components, instrumentation and electrical services, transfers of natural gas and refrigerants, fire protection, safety and security. It also mandates alternative requirements for vehicle fueling for industrial and commercial facilities using American Society of Mechanical Engineers (ASME) pressure vessel containers. This standard includes requirements for LNG facilities to withstand substantial earthquakes. The NFPA standard for level of design means that the LNG facilities are strongly fortified for other events such as wind, flood, earthquakes and blasts. The latest update of NFPA 59A was published in 2001.

- NFPA 57 *Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems* - This standard covers vehicle fuel systems, LNG fueling facilities, installation requirements for ASME tanks, fire protection, safety and security for systems on board vehicles and infrastructure storing 70,000 gallons of LNG or less.

European standards include the following.

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[42]. See footnote 32. The NFPA began developing NFPA 59A in 1960 by a committee of the American Gas Association and was adopted in 1967.

- EN 1473 - The European Norm standard EN 1473 *Installation and equipment for Liquefied Natural Gas - Design of onshore installations* evolved out of the British Standard, BS 7777[43] in 1996. It is a standard for the design of onshore LNG terminals. This standard is not prescriptive but promotes a risk-based approach for the design.
- EN 1160 – *Installation and equipment for Liquefied Natural Gas – General Characteristics of Liquefied Natural Gas* contains guidance on properties of materials commonly found in LNG facility that may come into contact with LNG.
- EEMUA 147[44] - *Recommendations for the design and construction of refrigerated liquefied gas storage tanks*. This document contains basic recommendations for the design and construction of single, double and full containment tanks for the bulk storage of refrigerated liquefied gases (RLGs) down to -165°C, covering the use of both metal and concrete materials.

Regulations applicable to LNG ships include:

- 33 CFR 160.101 *Ports and Waterways Safety: Control of Vessel and Facility Operations*. This U.S. federal government regulation describes the authority exercised by District Commanders and Captains of the Ports to insure the safety of vessels and waterfront facilities, and the protection of the navigable waters and the resources therein. The controls described in this subpart are directed to specific situations and hazards.
- 33 CFR 165.20 *Regulated Navigation Areas and Limited Access Areas: Safety zones.* A safety zone is a water area, shore area, or water and shore area to which, for safety or environmental purposes, access is limited to authorized persons, vehicles, or vessels. It may be stationary and described by fixed limits, or described as a zone around a vessel in motion. It is commonly used for ships carrying flammable or toxic cargoes, fireworks barges, long tows by tugs, or events like high speed races.

[43]British Standards Institution (BSI) BS 7777. See footnote 17.
[44] See footnote 18.

- 33 CFR 165.30 *Regulated Navigation Areas and Limited Access Area: Security Zones*. This section defines a security zone as an area of land, water, or land and water that is so designated by the Captain of the Port or District Commander for such time as is necessary to prevent damage or injury to any vessel or waterfront facility, to safeguard ports, harbors, territories, or waters of the United States or to secure the observance of the rights and obligations of the United States. It also determines the purpose of a security zone -- to safeguard vessels, harbors, ports, and waterfront facilities from destruction, loss, or injury from sabotage or other subversive acts, accidents, or other causes of a similar nature in the United States and all territory and water, continental or insular, that is subject to the jurisdiction of the United States. Generally, it covers ships with flammable or toxic cargoes, cruise ships, naval ships, and nuclear power facilities and airports.

APPENDIX 3: WHO REGULATES LNG IN THE U.S.?

A schematic of regulatory entities and their relationships with each other and integration with international standards organizations is shown in Figure 26.

Figure 26. U.S. LNG Regulators

Onshore/Marine

Federal Agencies

- The Department of Energy
- Federal Energy Regulatory Commission (FERC)
- The U.S. Coast Guard (USCG)
- The Department of Transportation (DOT)
- The U.S. Environmental Protection Agency (EPA)
- U.S. Minerals Management Service
- U.S. Fish and Wildlife Service
- U.S. Department of Labor Occupational Safety & Health Administration (OSHA)
- U.S. Army Corps of Engineers

Offshore

Federal Agencies

- The Department of Energy
- The U.S. Coast Guard (USCG)
- The Department of Transportation (DOT)
- U.S. Fish and Wildlife Service
- National Oceanic and Atmospheric Administration
- U.S. Department of Labor Occupational Safety & Health Administration (OSHA)
- U.S. Army Corps of Engineers

State & Local Agencies

- Departments of environmental protection
- Fire departments
- Police

Non-Governmental Regulators/Standards Organizations

- The National Fire Protection Association (NFPA)
- American Society of Mechanical Engineers (ASME)
- The American Society of Civil Engineers (ASCE)
- The American Petroleum Institute (API)
- The American Concrete Institute (ACI)
- The American Society for Testing and Materials (ASTM)

Federal, state, and local authorities have the power to regulate the construction and operation of LNG facilities. Federal regulation of the industry is by far the most comprehensive, and there is a separate regulatory requirement for the construction and operation of LNG facilities. All governmental entities have some ability to regulate each phase of a facility's life. Determination of jurisdiction between federal and state agencies is a constitutional matter. Both states and the U.S. Congress may regulate activities.

Federal Regulation of LNG

LNG facilities fall under the regulation of a large number of federal agencies, including, but not limited to, the U.S. Coast Guard, Department of Transportation, Federal Energy Regulatory Commission, Environmental Protection Agency, U.S. Department of Labor Occupational Safety & Health Administration, Customs and Immigration. Four federal agencies have specific regulatory enforcement roles spelled out by statutes. These agencies are the Department of Energy, the Federal Energy Regulatory Commission, the Department of Transportation, and the U.S. Coast Guard. The roles of these agencies and their LNG-specific regulations are described in this appendix. These agencies and others also enforce regulations that are applied to many parts of the energy industry.

The Department of Energy (DOE)

All imports of LNG require a certificate for importation from the DOE. The process of getting a certificate requires a study by the DOE. However, this process is automatic for countries that are free trade nations. The regulatory role of the DOE is only to monitor the amount of LNG being imported and exported, and to protect American energy supplies via the certification process.

The Federal Energy Regulatory Commission (FERC)

LNG onshore terminals in the U.S. had historically been treated like interstate pipelines, thus allowing FERC to regulate these facilities. The FERC has jurisdiction over onshore import and export facilities, and some peak shaving facilities, and thus, regulatory control over most of existing U.S. LNG facilities. The FERC has significant oversight responsibility for LNG import and export facilities during their construction. The FERC can approve or reject the location of all LNG import and export facilities prior to construction. One step of the review process requires a safety review and analysis of the design. The design of LNG facilities must conform to the National Fire Protection Association's (NFPA) LNG standards, such as NFPA 59A. FERC also regulates the modification and expansion of LNG onshore facilities.

The FERC prepares an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) for all onshore facilities as part of the certification process to construct or operate an LNG facility. In addition to evaluating environmental concerns, the FERC reviews the engineering design of the facility and monitors construction of the project.

The Department of Transportation (DOT)

The DOT plays a major role in ensuring the safe operation of LNG facilities by reviewing construction and operation of facilities. The Secretary of Transportation is charged with prescribing minimum safety standards concerning the location, design, installation, construction, initial inspection, and testing of a new LNG facility and offshore facilities. Specifically, DOT's Research and Special Programs Administration (RSPA), Office of Pipeline Safety (OPS), oversees federal safety standards for LNG facilities. These standards include requirements for site location, design, construction, operations and maintenance of an LNG facility, as well as personnel qualifications and training, fire protection, and security. Additionally, DOT has specially trained personnel who conduct periodic on-site inspections of LNG facilities.

For interstate LNG facilities there is some jurisdictional overlap in the review of the location, design and construction of the facility. Although FERC approves the site, the Office of Pipeline Safety and a state agency authorized to act as OPS's agent may complement FERC's efforts in reviewing the design and monitoring the construction of an LNG facility. The certificate issued by FERC may contain conditions that reflect input from OPS or could attach conditions in addition to their requirements.

The U.S. Coast Guard (USCG)

In U.S. waters, the USCG regulates U.S. flag LNG ships and barges. The USCG has regulatory authority over their design, construction, manning, and operation, and the duties of their officers and crew. USCG regulations focus on safety. One way it provides oversight is through onboard inspection when LNG ships at the berth to confirm compliance with the prescribed regulations and with safety standards. These inspections are also conducted on foreign flag ships when in U.S. waters.

The USCG works with terminal and ship operators to ensure that the policies and procedures in place conform to required standards. The USCG also works with operators to conduct emergency response drills and joint exercises to test response plans. The USCG ensures that operators have adequate safety and environmental protection equipment and procedures to respond to an incident.

In addition to this oversight function the USCG determines the suitability of a waterway to transport LNG safely, and it requires that operation and emergency manuals be submitted for the ports where ships will operate. They also create safety rules for specific ports in order to minimize the chance of accidents. At LNG export or import terminal facilities, the USCG has jurisdiction over the marine transfer area which is the part of a waterfront facility between the ship and the last manifold valve immediately before the receiving tanks.

In November 2002, the U.S. Deepwater Port Act was amended by the Maritime Transportation Safety Act (MTSA) to include natural gas. As a result of this amendment the USCG now regulates deepwater LNG ports.

The U.S. Environmental Protection Agency (EPA)

The EPA establishes air and water standards for all LNG operations, and controls air, water and land pollution.

State regulation of LNG

Some states have specific regulations that pertain to LNG; however, there is no national standard for regulation at the state level. Some regulatory agencies (e.g. state departments of environmental protection) are involved in granting permits for specific activities with potential adverse environmental impacts (such as air permits, dredge material disposal).

Local regulation of LNG

Local government agencies may also have requirements for the construction, operation and maintenance of LNG terminals. State and local agencies like the fire department and police also have jurisdiction on the basis of protecting the safety of the surrounding area.

Non-Governmental Regulation of LNG

The National Fire Protection Association (NFPA) develops fire safety codes and standards drawing upon the technical expertise of persons from diverse professional backgrounds that form technical committees. These committees address concerns about specific activities or conditions related to fire safety. The members of these committees use an open consensus process to develop standards for minimizing the possibility and effects of fire. NFPA has adopted two comprehensive standards, NFPA 59A and NFPA 57, that relate to LNG.

NFPA 59A Standard for the Production, Storage and Handling of Liquefied Natural Gas (LNG) 2001 Edition describes the basic methods of equipment fabrication as well as LNG installation and operating practices that provide for protection of persons and property. It also "provides guidance to all persons concerned with the construction and operation of equipment for the production, storage, and handling of liquefied natural gas." This comprehensive standard contains detailed technical requirements to ensure safety of LNG facilities and operations, including general facility considerations, process systems, stationary LNG storage containers, vaporization facilities, piping systems and components, instrumentation and electrical services.

The standard also incorporates, by reference, technical standards developed by a number of other professional organizations, such as American Society of Mechanical Engineers (ASME)[45], the American Society of Civil Engineers (ASCE)[46], the American

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[45] American Society of Mechanical Engineers (ASME) http://www.asme.org/
[46] American Society of Civil Engineers (ASCE) http://www.asce.org/

Petroleum Institute (API)[47], the American Concrete Institute (ACI)[48], and the American Society for Testing and Materials (ASTM)[49]. (A complete list of these organizations appears in the last chapter of the NFPA standard.)

The NFPA is not empowered to enforce compliance with its codes and standards. Only regulatory bodies or political entities that have enforcement powers can set the standards that the NFPA creates to regulate the industry. An example is when FERC uses the NFPA standards in their safety review of LNG facilities.

[47] American Petroleum Institute (API) http://api-ec.api.org
[48] American Concrete Institute (ACI) http://www.aci-int.org/
[49]American Society for Testing and Materials (ASTM) http://www.astm.org.

APPENDIX 4: RISK PERCEPTION

In many aspects of daily life, *risk* of a certain event is very often perceived to be much different from reality. Sometimes potentially dangerous activities can become so commonplace and accepted that the risk associated with those activities can be taken for granted, such as driving a car or flying in a plane. In other cases, the focus on worst-case events overshadows the real probability that such events will ever occur. In many such instances, worst-case scenarios are assumed without taking into consideration the numerous steps taken to prevent them. Risk is a combination of not only the consequence of an event, but also the probability of the event occurring. A high consequence event with a low probability of occurrence may be similar on a “risk basis” to a low consequence event with a high-probability of occurrence.

Potential damage and injuries from an LNG incident would depend on initiating events, volume and location of LNG release, release rate, wind direction and speed, and other factors. However, the quantitative calculation of probabilities of such an event actually can only be done if sufficient data exists.

Terrorism

Unexpected risks are, of course, different from routine risks with regard to uncertainty about whether or when they could take place. There must be a general enforcement of security to protect all types of facilities and public places, including LNG operations, from acts of violence. With respect to unexpected risks such as terrorism, a system of safeguards is already in place.

LNG tanks, whether on ships, on land, or offshore, require exceptionally large amounts of force to cause damage. Because the amount of energy required to breach containment is so large, in almost all cases the major hazard presented by terrorists is a fire, not an explosion. If an aircraft crashed into an LNG facility, the impact would almost certainly cause a fire fueled initially by the aircraft fuel. It may also ignite the LNG, causing a larger fire at the facility. Emergency fire detection and protection at the LNG facility/ship would be used in such an event. Danger to the public from this type of event would be reduced or eliminated by the separation distance of the facility.

Rigorous siting reviews coupled with separation and distance requirements in U.S. safety codes[50] minimize risk to the public from land-based facilities. According to the opinion of Project Technical Liaison Associates, Inc. (PTL), "LNG land-based facilities are sited to very stringent design and construction codes and standards. These codes require that 'worst-case' accident scenarios be used in the siting and design of these facilities."[51]

The U.S. Coast Guard (USCG) which by Federal law has the responsibility for implementing safety regulations that apply to LNG marine operations in the U.S. is now part of the new U.S. Department of Homeland Security. For all vessels of special interest, including LNG ships, the USCG enforces strict measures towards terror threat protection. Measures taken to prevent terrorism on LNG facilities and ships worldwide include inspections and patrols, action plans for security breach, and emergency communication systems as well as intelligence gathering. These same measures are also used at other critical facilities, operations and ships - such as passenger ships, oil tankers, containerships etc.

Earthquakes

When estimating the risk of LNG projects, the companies involved in LNG facilities consider the danger of strong ground movements and failures due to seismic activity, liquefaction and landslides in the area. The seismic design requirements are outlined in the NFPA 59-A 2001. Major earthquakes can cause severe damage if the facilities are not designed to withstand such events, so the companies conduct regional and site-specific studies to see if the areas are seismically active. These factors are then taken into account during planning and design stages. The design of LNG tanks can accommodate regional seismic activity in locations of potential risk. There are no known incidences of LNG storage tank failures due to seismic activity. In fact, in 1995, none of the LNG storage tanks in the Kobe, Japan area were damaged during a 6.8 earthquake on the Richter scale.

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[50] See footnote 31.
[51] Lewis, James P. and Sheila A. McClain, Project Technical Liaison Associates, Inc. (PTL): *LNG Security: Reality and Practical Approaches*, LNG: Economics & Technology Conference, January 2003.

Japan is one of the world's largest users of LNG and has many LNG storage tanks. Table 3 shows the different LNG facilities in the U.S. and Japan. Japan is also one of the more seismically active areas of the world. Damage to its LNG facilities from the most severe earthquakes has been limited to that of natural gas pipelines. CEE conducted a separate case study on Japan's long experience with LNG and safety record.[52]

Table 3. LNG Facilities in the U.S. and Japan

	U.S.*	**Japan****
Liquefaction Terminals	1	
Re-gasification Terminals	4	22
Peak shaving Facilities	57	
Satellite Storage Facilities (without liquefaction)	39	26
Others	12	
	113	48
	* as of 2002	**as of 1998
Sources: EIA, Japan Gas Association		

Maritime Incidents

The history of the LNG industry has shown that maritime incidents with severe LNG releases are very rare. Over the industry's 60-year history of 59,000 voyages, there has never been a spill from a ship into the water from either a collision or grounding. LNG ships are well designed and well maintained, which reduces the chances and severity of incidents. Their designs prevent breaching of cargo tanks and involvement of multiple tanks in accidents. Potential hazards could come from ignition of LNG pool fires or a vapor cloud.

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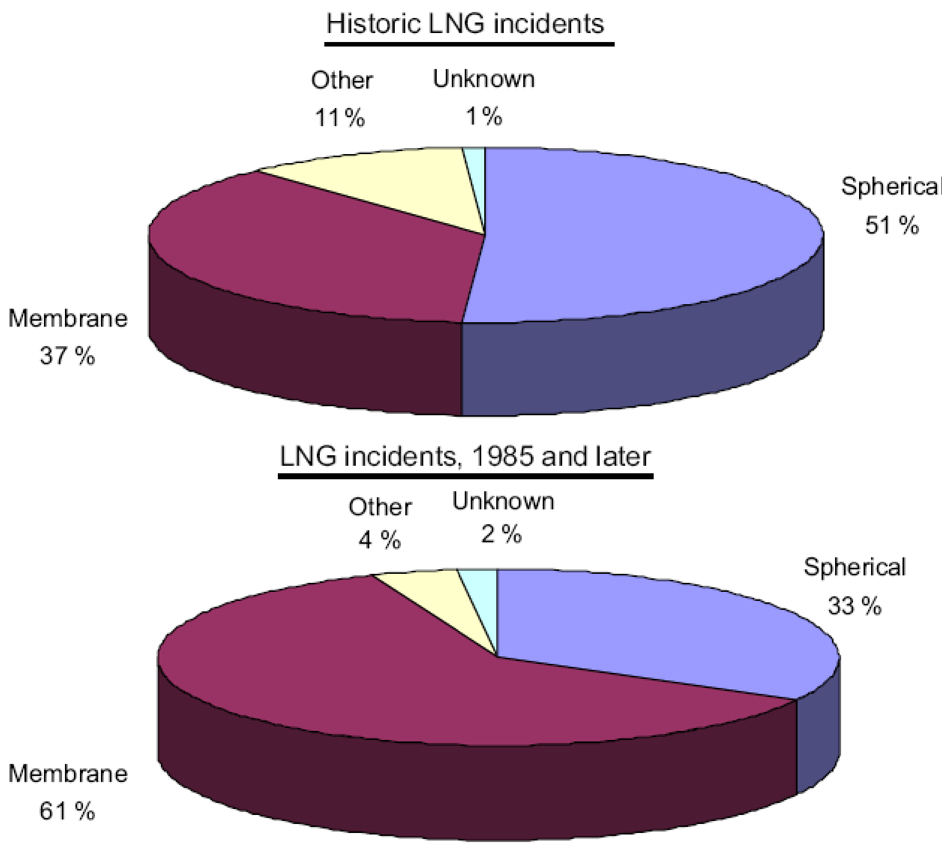
[52] Contact the CEE for details and availability.

Figure 27. LNG incidents before and after 1985 by ship type



Source: Erik Vanem, Pedro Antao, Ivan Østvik, Francisco Del Castillo de Comas, "Analysing the risk of LNG carrier operations". Reliability Engineering and System Safety 93 (2008) 1328–1344

Operational Incidents

Operational incidents - incidents resulting from human error, equipment failures, or both can occur in any industry and any facilities. In the LNG facilities, it could happen during unloading, storage, vaporizing and pipeline transmission or other stages of production. Such errors could result in a spill or a fire. LNG facilities and ships have advanced monitoring and control systems that make an incident unlikely to occur compared to other releases. Consequences of the majority of potential incidents would be contained on site and managed before they could result in significant damage.

APPENDIX 5: MAJOR LNG INCIDENTS[53]

According to the U.S. Department of Energy,[54] over 60 years of the industry's life, eight marine incidents worldwide have resulted in spillage of LNG, with some causing deck-plating damage under the manifold piping due to brittle fracture. There were no LNG cargo related fires. The design of LNG ships has been a contributing factor in avoiding damage to the LNG containment tanks.

With the exception of the 1944 Cleveland fire, all LNG-related injuries have occurred within an LNG facility. There has never been an LNG shipboard fatality. No death or serious incidents involving LNG has occurred in the United States since the Cove Point incident in 1979, although there were several incidents outside the U.S. since then (see Table 4 below).

Table 4. Major Energy-related Incidents Worldwide, 1907-2007

	Facility	Date	Location	Description	Fatalities	Cost ($millions)
1	Coal mine	December 6, 1907	Monongah, West Verginia USA	Underground explosion traps workers and destroys railroad	362	162
2	Coal mine	February 27, 1908	San Juan de Sabinas, Coahuila, Mexico	Mine shaft completely collapses	201	12
3	Coal mine	September 30, 1908	Palau Coal Mine, Coahuila, Mexico	Explosion and fire collapse multiple shafts	100	8
4	Coal mine	February 16, 1909	Stanley, England	Explosion and fire destroys entire mine	168	11
5	Coal mine	November 13, 1909	Cherry, Illinois, USA	Fire and explosion collapse multiple shafts	259	42
6	Coal mine	October 22, 1913	Dawson, New Mexico, USA	Fire induces explosion that buries workers	263	5

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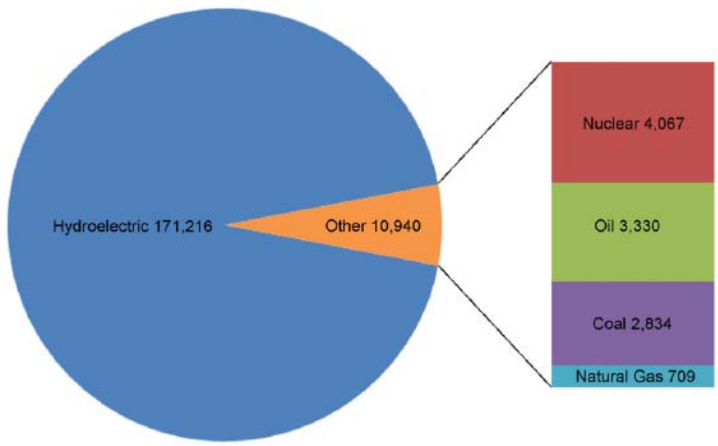
[53] Much of the materials in this section are taken West, H.H. and M.S. Mannan, Texas A&M University: *LNG Safety Practice & Regulation: From 1944 East Ohio Tragedy to Today's Safety Record,* AIChE meeting, April 2001 and CH-IV International: *Safety History of International LNG Operations*, November 2002.
[54] Juckett, Don, U.S. Department of Energy, *Properties of LNG*. LNG Workshop, MD, 2002.

	Facility	Date	Location	Description	Fatalities	Cost ($millions)
7	Coal mine	October 14, 1913	Cardiff, Wales	Mine shaft completely collapses	439	12
8	Coal mine	June 19, 1914	Hillcrest, Alberta, Canada	Fire and explosion collapse multiple shafts	189	7
9	Coal mine	June 5, 1919	Wilkes-Barre, Pennsylvania, USA	Underground explosion collapses facility	92	3
18	LNG Plant	October 20, 1944	Cleveland, Ohio, USA	Explosion at LNG Facility destroys 1 square mile of Cleveland	130	890
33	LNG facility	May 3, 1965	Canvey Island, UK	Explosion during LNG transfer operation	1	2
51	LNG facility	March 18, 1971	La Spezia LNG Import Terminal, Italy	The LNG vessel Esso Brega leaks 2000 tons of fuel	0	1
64	LNG facility	February 10, 1973	Staten Island, New York, USA	LNG pipeline leaks at industrial facility causing fire and explosion	40	15
95	LNG facility	April 18, 1977	Arzew, Algeria	LNG releases from storage facility, causing fire and explosion	1	1
113	LNG facility	October 6, 1979	Cove Point, Maryland, USA	Fire and explosion at Cove Point LNG facility	1	9
183	LNG facility	May 10, 1988	Boston, Massachusetts, USA	LNG facility spills 30,000 gal	0	12
212	LNG facility	December 20, 1993	Bontang, Indonesia	LNG facility leaks fuel into underground sewer system	0	15
263	LNG facility	January 19, 2004	Skikda, Algeria	Explosion and fire occur at Skikda LNG facility	27	54

Source: Benjamin K. Sovacool, "The costs of failure: A preliminary assessment of major energy accidents, 1907–2007". Energy Policy 36 (2008) 1802–1820

In fact, recent study[55] showed that LNG industry proved to be the safest one among all energy-related sectors both in terms of social and economic costs in the past century (see Figure 28 below). The study analyzed major 279 incidents world-wide that have been responsible for $41 billion in property damage and 182,156 deaths.

Figure 28. Energy accident fatalities by source, 1907–2007



Source: Benjamin K. Sovacool, "The costs of failure: A preliminary assessment of major energy accidents, 1907–2007". Energy Policy 36 (2008) 1802–1820

H.H. West and M.S. Mannan of Texas A&M University[56] concluded that "The worldwide LNG industry has compiled an enviable safety record based on the diligent industry safety analysis and the development of appropriate industrial safety regulations and standards." Below is a brief description of significant incidents that have occurred at LNG facilities.

Cleveland, Ohio, 1944

In 1939, the first commercial LNG peak shaving facility was built in West Virginia. In 1941, the East Ohio Gas Company built a second facility in Cleveland. The peak shaving 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. The tank failed shortly

[55] Benjamin K. Sovacool, "The costs of failure: A preliminary assessment of major energy accidents, 1907–2007", Energy Policy 36 (2008) 1802–1820.
[56] See footnote 53.

after it was placed in service. 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."[57]

Staten Island, New York, February 1973

In February 1973, an industrial incident unrelated to the presence of LNG occurred at the Texas Eastern Transmission Company peak shaving facility on Staten Island. In February 1972, the operators, suspecting a possible leak in the tank, took the facility out of service. Once the LNG tank was emptied, tears were found in the mylar lining. During the repairs the mylar liner was ignited. The resulting fire caused the temperature in the tank to rise, generating enough pressure to dislodge a 6-inch thick concrete roof, which then fell on the workers in the tank, killing 40 people.

The Fire Department of the City of New York report of July 1973[58] determined that the incident was clearly a construction incident and not an "LNG incident." In 1998, the New York Planning Board, while re-evaluating a moratorium on LNG facilities, concluded the following: “The government regulations and industry operating practices now in place would prevent a replication of this incident. The fire involved combustible construction materials and a tank design that are now prohibited. Although the exact causes may never be known, it is certain that LNG was not involved in the incident and the surrounding areas outside the facility were not exposed to risk.”[59]

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[57] U.S. Bureau of Mines, *Report on the Investigation of the Fire at the Liquefaction, Storage, and Re-gasification Facility of the East Ohio Gas Co., Cleveland, Ohio, October 20, 1944*, February 1946.

[58] Fire Department of the City of New York, *Report of Texas Eastern LNG Tank Fatal Fire and Roof Collapse, February 10, 1973*, July 1973.

[59] New York Energy Planning Board, *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.

Cove Point, Maryland, October 1979[60]

In October 1979, an explosion occurred within an electrical substation at the Cove Point, MD receiving terminal. LNG leaked through an inadequately tightened LNG pump electrical penetration seal, vaporized, passed through 200 feet of underground electrical conduit, and entered the substation. Since natural gas was never expected in this building, there were no gas detectors installed. The normal arcing contacts of a circuit breaker ignited the natural gas-air mixture, resulting in an explosion. The explosion killed one operator in the building, seriously injured a second and caused about $3 million in damages.

This was an isolated incident caused by a very specific set of circumstances. The National Transportation Safety Board[61] found that the Cove Point Terminal was designed and constructed in conformance with all appropriate regulations and codes. However, as a result of this incident, three major design code changes were made at the Cove Point facility prior to reopening. Today, those changes are now applicable industry-wide.

Given all of the safety and security measures provided in the LNG value chain, there is a low probability of a serious incident. However the consequences of failure at land-based terminals, as with other energy facilities, can be quite large if proper safety precautions and protections are not employed.

The small number of safety incidents that have occurred demonstrates the outstanding safety of the LNG industry. A table at the end of this appendix lists other LNG related incidents, along with some of the critical improvements that have been made.

LNG Vehicle Incidents

A methane explosion occurred inside an LNG-powered 60-foot articulated bus during servicing on December 6, 1992. The vehicle had just been delivered and was being readied for operation on LNG. The manufacturer's representative was

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[60] The content in this section is taken from CH-IV International Report *Safety History of International LNG Operations*, June 2002.
[61] National Transportation Safety Board Report, *Columbia LNG Corporation Explosion and Fire; Cove Point, MD; October 6, 1979*, NTSB-PAR-80-2, April 16, 1980.

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.

Table 5. Major LNG Incidents[62]

Incident Date	Ship / Facility Name	Location	Ship Status	Injuries/ Fatalities	Ship/ Property Damage	LNG Spill/ Release	Comment
I944	East Ohio Gas LNG Tank	Cleveland	NA	128 deaths	NA	NA	Tank failure and no earthen berm. Vapor cloud formed and filled the surrounding streets and storm sewer system. Natural gas in the vaporizing LNG pool ignited.
1965		Canvey Island, UK	A transfer operation	1 seriously burned		Yes	
1965	Jules Vernet		Loading	No	Yes	Yes	Overfilling. Tank cover and deck fractures.
1965	Methane Princess		Disconnecting after discharge	No	Yes	Yes	Valve leakage. Deck fractures.
1971	LNG ship Esso Brega, La Spezia LNG Import Terminal	Italy	Unloading LNG into the storage tank	NA	NA	Yes	First documented LNG Rollover incident. Tank developed a sudden increase in pressure. LNG vapor discharged from the tank safety valves and vents. Tank roof slightly damaged. No ignition
1973	Texas Eastern Transmission, LNG Tank	Staten Island	NA	40 killed	No	No	Industrial incident unrelated to the presence of LNG. During the repairs, vapors associated with the cleaning process apparently ignited the mylar liner. Fire caused temperature in the tank to rise, generating enough pressure to dislodge a 6-inch thick concrete roof, which then fell on the workers in the tank.
1973		Canvey Island, UK	NA	No	Yes	Yes	Glass breakage. Small amount of LNG spilled upon a puddle of rainwater, and the resulting flameless vapor explosion, called a rapid phase transition (RPT), caused the loud "booms." No injuries resulted.
1974	Massachusetts		Loading	No	Yes	Yes	Valve leakage. Deck fractures.
1974	Methane Progress		In port	No	Yes	No	Touched bottom at Arzew.
1975	Philadelphia Gas Works		NA	No	Yes	NA	Not caused by LNG. An iso-pentane intermediate heat transfer fluid leak caught fire and burned the entire vaporizer area.
1977	Arzew	Algeria	NA	1 worker frozen to death	NA	Yes	Aluminum valve failure on contact with cryogenic temperatures. Wrong aluminum alloy on replacement valve. LNG released, but no vapor ignition.
1977	LNG Aquarius		Loading	No	No	Yes	Tank overfilled.

[62] Much of the materials in this section are taken from Lloyd's Register's Risk Assessment Review of the Marine Transportation of Liquefied Natural Gas, STD Report #3000-1-2, September 1992; West, H.H. and M.S. Mannan, Texas A&M University: *LNG Safety Practice & Regulation: From 1944 East Ohio Tragedy to Today's Safety Record,* AIChE meeting, April 2001 and CH-IV International: *Safety History of International LNG Operations*, November 2002.

Incident Date	Ship / Facility Name	Location	Ship Status	Injuries/ Fatalities	Ship/ Property Damage	LNG Spill/ Release	Comment
1979	Columbia Gas LNG Terminal	Cove Point, Maryland	NA	1 killed 1 seriously injured	Yes	Yes	An explosion occurred within an electrical substation. LNG leaked through LNG pump electrical penetration seal, vaporized, passed through 200 feet of underground electrical conduit, and entered the substation. Since natural gas was never expected in this building, there were no gas detectors installed in the building. The normal arcing contacts of a circuit breaker ignited the natural gas-air mixture, resulting in an explosion.
1979	Mostefa Ben-Boulaid Ship	?	Unloading	No	Yes	Yes	Valve leakage. Deck fractures.
1979	Pollenger Ship	?	Unloading	No	Yes	Yes	Valve leakage. Tank cover plate fractures.
1979	El Paso Paul Kayser Ship		At sea	No	Yes	No	Stranded. Severe damage to bottom, ballast tanks, motors water damaged, bottom of containment system set up.
1980	LNG Libra		At sea	No	Yes	No	Shaft moved against rudder. Tail shaft fractured.
1980	LNG Taurus		In port	No	Yes	No	Stranded. Ballast tanks all flooded and listing. Extensive bottom damage.
1984	Melrose		At sea	No	Yes	No	Fire in engine room. No structural damage sustained – limited to engine room.
1985	Gradinia		In port	No	Not reported	No	Steering gear failure. No details of damage reported.
1985	Isabella		Unloading	No	Yes	Yes	Cargo valve failure. Cargo overflow. Deck fractures.
1989	Tellier		Loading	No	Yes	Yes	Broke moorings. Hull and deck fractures.
1990	Bachir Chihani		At sea	No	Yes	No	Sustained structural cracks allegedly caused by stressing and fatigue in inner hull.
1993	Indonesian liquefaction facility	Indonesia	NA	No	NA	NA	LNG leak from open run-down line during a pipe modification project. LNG entered an underground concrete storm sewer system and underwent a rapid vapor expansion that overpressured and ruptured the sewer pipes. Storm sewer system substantially damaged.
2002	LNG ship Norman Lady	East of the Strait of Gibraltar	At sea	No	Yes	No	Collision with a U.S. Navy nuclear-powered attack submarine, the U.S.S Oklahoma City. In ballast condition. Ship suffered a leakage of seawater into the double bottom dry tank area.
2004	Skikda LNG terminal	Algeria	NA	Yes	Yes	Yes	Unit 40 at the Skikda LNG plant exploded. Within seconds, the adjacent Units 20 and 30 also exploded in an apparent chain reaction. The blast spread outward, damaging surrounding structures and facilities--including a nearby power plant, one of the berths at the Skikda harbor and numerous homes and

Incident Date	Ship / Facility Name	Location	Ship Status	Injuries/ Fatalities	Ship/ Property Damage	LNG Spill/ Release	Comment
							other buildings in the community.
2009	South Hook LNG terminal	UK	NA	No	No	Yes	A maximum of ten litres of LNG was spilled and "immediately vapourised", because of the unintended activation of the emergency shutdown system, which caused powered emergency release couplings to separate, discharging LNG.
2010	Montoir de Bretagne terminal	France	Unloading	No	Yes	No	The incident occurred when liquid passed into the gas take-off line during discharge operations. The damage sustained extended to part of the ship's manifold and its feed lines.
2010	Withnell Bay facility	Australia	Loading	No	Yes	Yes	The ship suffered cryogenic burns when 2,000 to 4,000 litres of LNG were spilt.
2011	Yung An LNG terminal	Taiwan	Unloading	No	NA	NA	The vessel's master decided to suspend the discharge and move the ship off the berth but the problems were eventually rectified and the vessel returned to complete the discharge of its cargo.
2011	Pyeongtaek LNG terminal	South Korea	Unloading	No	Yes	Yes	The ship disconnected from the berth after what was described as a very small leak of LNG was reported around the top of one emergency release coupler shortly after a scheduled overhaul of the unloading arms had been completed. Seals and ball valves were replaced on the unloading arms and discharge recommenced using the remaining two arms.

APPENDIX 6: GLOSSARY OF TERMS[63,64]

TERM	DEFINITION
Autoignition temperature	The lowest temperature at which a gas will ignite after an extended time of exposure (e.g., several minutes).
British Thermal Unit (BTU)	A BTU is the amount of heat required to change the temperature of one pound of water by one degree Fahrenheit.
Cryogenic	Refers to low temperature and low temperature technology. There is no precise temperature for an upper boundary but -100°F is often used.
Density	A description of oil by measurement of its volume to weight ratio.
Explosion	The sudden release or creation of pressure and generation of high temperature as a result of a rapid change in chemical state (usually burning), or a mechanical failure.
Fahrenheit degrees (F)	A temperature scale according to which water boils at 212 and freezes at 32 Fahrenheit degrees. Convert to Centigrade degrees (C) by the following formula: (F-32)/1.8= C.
Flammability limit	Of a fuel is the concentration of fuel (by volume) that must be present in air for an ignition to occur when an ignition source is present.
Impoundment	Spill control for tank content designed to limit the liquid travel in case of release. May also refer to spill control for LNG piping or transfer operations.
Middle distillates	Products heavier than motor gasoline/naphtha and lighter than residual fuel oil. This range includes heating oil, diesel, kerosene, and jet kero.
Mole Percent	Mole is a short form of molecular weight. Mole fraction or mole percent is the number of moles of a component of a mixture divided by the total number of moles in the mixture.
MTPA	Million Tonnes per Annum. Tonnes or Metric Ton is approximately 2.47 cubic meter of LNG.
MW	Molecular Weight
Peak shaving LNG Facility	A facility for both storing and vaporizing LNG intended to operate on an intermittent basis to meet relatively short term peak gas demands. A peak shaving facility may also have liquefaction capacity, which is usually quite small compared to vaporization capacity at such facility.
Risk and hazard	Risk and hazard are not the same. Risk means the realization of potential damage, injury or loss; hazard means a condition with potential for initiating an incident or incident.

[63] Phillips Petroleum Company.
[64] Poten & Partners, http://www.poten.com/?URL=ut_glossary.asp.

TERM	DEFINITION
Stranded Gas	Gas that is not near a customer and therefore does not justify the construction of a pipeline.
Sweetening	Processing to remove sulfur. Hydrodesulfurization, for instance, can produce sweet catalytic cracker materials useful for the production of fuels and chemicals. Caustic washing can sweeten sour natural gasolines to make them suitable for motor gasoline blending.

APPENDIX 7: CONVERSION TABLE

Natural gas and LNG	To billion cubic metres NG	billion cubic feet NG	million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
From			**Multiply by**			
1 billion cubic metres NG	1	35.3	0.90	0.73	36	6.29
1 billion cubic feet NG	0.028	1	0.026	0.021	1.03	0.18
1 million tonnes oil equivalent	1.111	39.2	1	0.805	40.4	7.33
1 million tonnes LNG	1.38	48.7	1.23	1	52.0	8.68
1 trillion British thermal units	0.028	0.98	0.025	0.02	1	0.17
1 million barrels oil equivalent	0.16	5.61	0.14	0.12	5.8	1

Crude oil*	To tonnes (metric)	kilolitres	barrels	U.S. gallons	tonnes/ year
From			**Multiply by**		
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
U.S. gallons	0.00325	0.0038	0.0238	1	–
Barrels/day	–	–	–	–	49.8

*Based on worldwide average gravity.

Products	To convert barrels to tonnes	tonnes to barrels	kilolitres to tonnes	tonnes to kilolitres
		Multiply by		
LPG	0.086	11.6	0.542	1.844
Gasoline	0.118	8.5	0.740	1.351
Distillate fuel oil	0.133	7.5	0.839	1.192
Residual fuel oil	0.149	6.7	0.939	1.065

Example: To convert **FROM** 1 million tons of LNG **TO** billion cubic feet of natural gas, multiply by 48.7 (100 million tons of **LNG** equals roughly 5000 billion cubic feet of **natural gas**).

Units

1 metric tonne = 2204.62 lb.

= 1.1023 short tons

1 kilolitre = 6.2898 barrels

1 kilolitre = 1 cubic metre

1 kilocalorie (kcal) = 4.187 kJ = 3.968 Btu

1 kilojoule (kJ) = 0.239 kcal = 0.948 Btu

1 British thermal unit (Btu) = 0.252 kcal = 1.055 kJ

1 kilowatt-hour (kWh) = 860 kcal = 3600 kJ = 3412 Btu

Calorific equivalents

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories
	42 gigajoules
	40 million Btu
Solid fuels	1.5 tonnes of hard coal
	3 tonnes of lignite
Gaseous fuels	See Natural gas and LNG table
Electricity	12 megawatt-hours

One million tonnes of oil produces about 4500 gigawatt-hours (=4.5 terawatt hours) of electricity in a modern power station.

The conversion factors above are taken from *BP Statistical Review of World Energy 2003*, which is available at http://www.bp.com/centres/energy/definitions/units.asp.