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LNG SAFETY AND SECURITY

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LNG SAFETY AND SECURITY¹

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*, introduced the reader to LNG and briefly discussed many of the key issues related to the LNG industry. This second paper deals with safety and security aspects of LNG operations. A third paper, *North America Supply-Demand Balances and Energy Security: a Role for LNG?* will provide an in-depth analysis of why more LNG may be needed to meet U.S. energy demand. All three papers, plus additional information, will be included in a complete fact book, *Guide to LNG in North America*. For a quick review of LNG facts, please see Appendix 1, LNG Frequently Asked Questions.

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.

¹ This publication was undertaken by the *Center for Energy Economics (CEE)* as the Institute for Energy, Law & Enterprise, University of Houston Law Center, through a research consortium *Commercial Frameworks for LNG in North America*. Sponsors of the consortium are BG LNG Services, BP Americas - Global LNG, Cheniere Energy, ChevronTexaco International Gas Group, ConocoPhillips Worldwide LNG, Dominion Energy, El Paso Energy, ExxonMobil Gas & Power Marketing Company, Freeport LNG, Sempra Energy Global Enterprises, Shell Gas & Power, Tractebel LNG North America/Distrigas of Massachusetts. The U.S. Department of Energy-Office of Fossil Energy provides critical support and coordination with other federal agencies and commissions. The Ministry of Energy and Industry, Trinidad & Tobago participates as an observer. Members of the technical advisory committee include American Bureau of Shipping (ABS), CH-IV International, Lloyd's Register, Project Technical Liaison Associates (PTL), and Society of International Gas Tanker and Terminal Operators (SIGTTO). Quest Consultants provided additional input. This report was prepared by Dr. Michelle Michot Foss, Executive Director, IELE; Mr. Fisoye Delano, Senior Researcher; Dr. Gürcan Gülen, Research Associate; with assistance from Ms. Ruzanna Makaryan, graduate student research assistant. The views expressed in this paper are those of the authors and not necessarily those of the University of Houston. Peer reviews were provided by LNG consortium advisors, UH faculty, and other outside experts.

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.

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°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

² The term “containment” is used in this document to mean safe storage and isolation of LNG.

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.

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. The CEE LNG web site, <http://www.beg.utexas.edu/energyecon/lng>, provides links to other industry, government and public information sources.

Introduction

This briefing paper is the second in a series that describes the liquefied natural gas (LNG) industry – its technology, markets, safety, security, environmental considerations, and the increasingly important role that LNG may play in the nation's energy future. The first paper, *Introduction to LNG*, introduced the reader to LNG and briefly discussed many of the topics related to the LNG industry. This second paper deals with safety and security aspects of LNG operations. A third paper, *North America Supply-Demand Balances and Energy Security: a Role for LNG?* will provide an in-depth analysis of why more LNG may be needed to meet U.S. energy demand. All three papers, plus additional information, will be included in a complete fact book, *Guide to LNG in North America*. For a quick review of main LNG facts, please see Appendix 1, LNG Frequently Asked Questions.

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 Appendix 6). 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 assurance 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°F (-160°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 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.

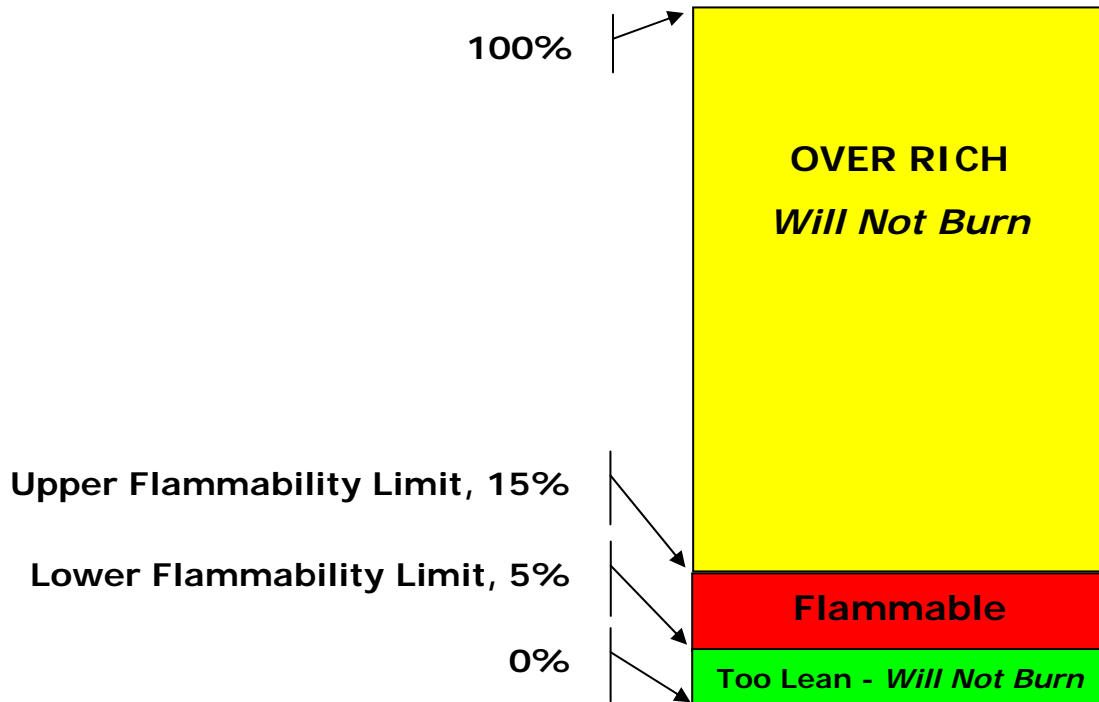
The *flammability range* is the range between the minimum and maximum concentrations of vapor (percent by volume) in which air and LNG vapors form a flammable mixture that can be ignited and burn.

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.

³ Cryogenic means extreme low temperature, generally below -100°F

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

Properties	LNG	Liquefied Petroleum Gas (LPG)	Gasoline	Fuel Oil
Other Health Hazards	None	None	Eye irritant, narcosis, nausea, others	Same as gasoline
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 clean up 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

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>

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 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) and 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 transport and store all of these fuels and, again, safety and security incidents are rare.

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 Hazards⁵

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.

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

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.

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

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).

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.

Earthquakes and Terrorism. The unexpected risks of earthquakes and terrorism are discussed in Appendix 5: 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 6). 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.

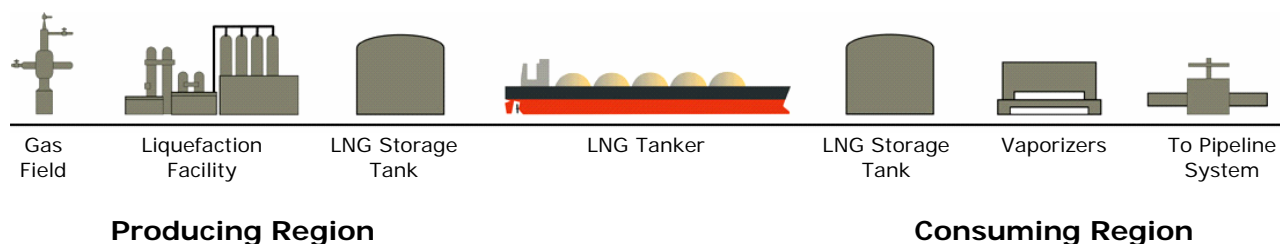
Our focus is on the properties of LNG, the particular hazards and risks that can develop from these properties and on the achievement of safety and security of LNG facilities. The major potential hazards of LNG and LNG vapors have been identified, analyzed, and taken into account, all to ensure the safe 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 4):

- *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 4. 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 Current LNG Value Chain in the U.S.

The U.S. differs little from other countries that use LNG, with one significant exception: because LNG constitutes such a small proportion of the domestic natural gas supply base, and because major new LNG receiving facilities have not been

constructed since the 1970s, LNG importation is not as familiar to the U.S. public as it is in other countries. Low levels of LNG industry activity over the years and our lack of familiarity with this fuel have several implications. First, new LNG import facilities constructed in the U.S. will benefit from the expertise gained elsewhere regarding 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. Second, operating practices at both existing and new LNG 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.

Most LNG facilities in the U.S. are peakshaving liquefaction and storage facilities, satellite storage facilities or marine import terminals. Only one facility in the U.S. is a baseload liquefaction facility.

Figure 5. LNG Liquefaction Facility in Kenai, Alaska



Source: ConocoPhillips

Baseload LNG liquefaction facilities 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

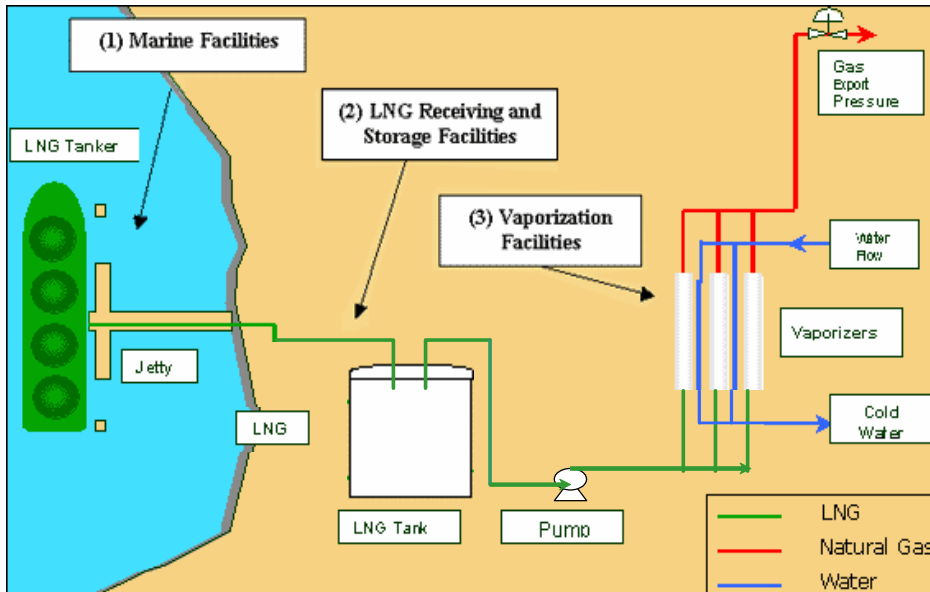
liquefaction facility located in Kenai, Alaska and owned jointly by ConocoPhillips and Marathon (shown in Figure 5) is the only baseload liquefaction export facility in the U.S., exporting LNG to Japan. No liquefaction export facilities are contemplated for the Lower 48 States. The U.S. is now a net importer of LNG and will probably remain so in the future.

Figure 6. A Peakshaving Facility



Peakshaving LNG facilities, as shown in Figure 6, 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. In the U.S., local distribution companies (LDCs) have used LNG for peakshaving during high demand periods for more than 60 years. This process has provided secure and reliable supplies of natural gas for use during periods of peak demand.⁸

Figure 7. Typical LNG Receiving Terminal/Re-gasification Facility



Source: BP LNG. Note that type of vaporization process and related water requirements may vary. See Appendix 2 for details.

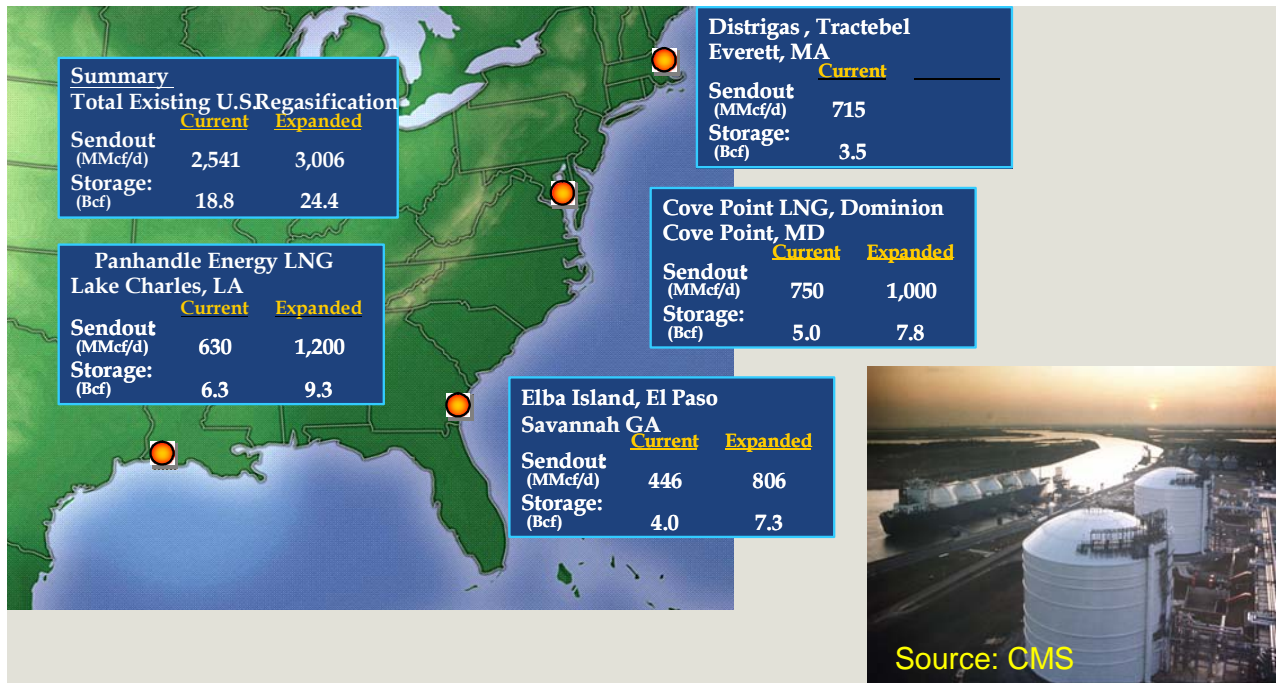
Perhaps most visible, given the number of plans to expand capacity (see *Introduction to LNG*), are *baseload LNG receiving and re-gasification facilities*. These facilities consist of terminals for LNG ships (1), LNG

receiving and storage facilities (2), and vaporizing facilities and supporting utilities (3), (see Figure 7). The marine baseload LNG re-gasification terminals in the

⁸ Cates, Rusty, International Gas Consulting, Inc., "LNG - Hedging Your Bets," LNG: Economics & Technology Conference, January, 2003.

continental U.S. are as follows (see Figure 8 below): Elba Island, Georgia (El Paso Corporation); Everett, Massachusetts (Tractebel); Cove Point, Maryland (Dominion Energy); and Lake Charles, Louisiana (Panhandle Energy, a Southern Union company).

Figure 8. Baseload Receiving and Re-gasification Facilities 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 LNGOneWorld, there were 145 existing *LNG ships*, as of Sept. 2003, with 56 on order.⁹ Eight LNG ships have been delivered in 2003, and orders for eight more have been placed. About 20 percent of the fleet is less than five years old. New LNG ships are designed to transport between 125,000 and 150,000 cubic meters (m³) of LNG,¹⁰ or about 2.8-3.1 billion standard cubic feet of natural gas. Various ship yards have begun designing larger LNG ships with a capacity greater than 200,000 m³. The use of larger ships, which enable LNG value chain economics

⁹ LNGOneWorld: <http://www.lngoneworld.com/LNGV1.nsf/Members/Index.html>.

¹⁰ Typically, LNG ship size is designated by cubic meters of liquid capacity.

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 9) 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 peakshaving duties, while others are dedicated to *vehicle fuel transfer* systems. LNG is usually delivered from marine terminals or peakshaving facilities to the satellite facilities by truck (shown in Figure 10).

Figure 9. A Satellite Storage Facility and Figure 10. An LNG Truck



Source: CH-IV International



Source: CH-IV International

There are about 240 LNG facilities worldwide. The U.S. has the largest number of those with 113 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, and New Jersey has five satellite LNG facilities, the second highest in the U.S.

Figure 11. U.S. LNG Facilities Storage Capacity

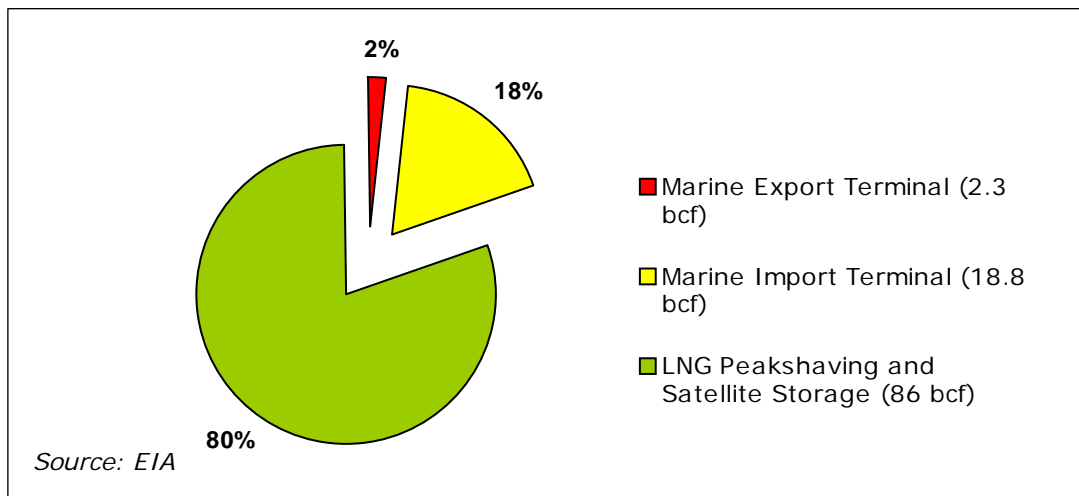
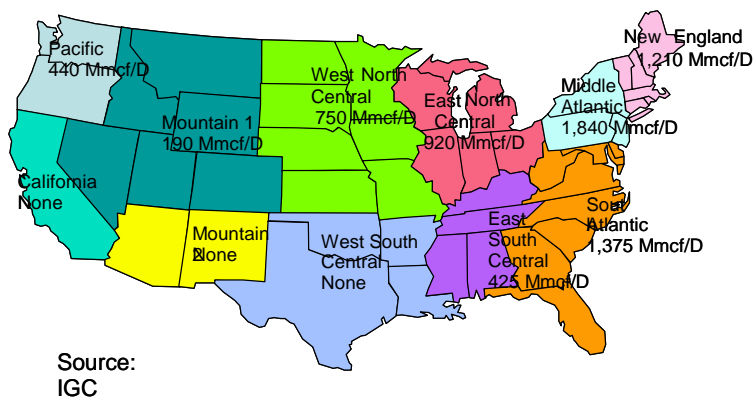


Figure 12. U.S. Regional LNG Storage Deliverability

U.S. Regional LNG Storage Deliverability



According to the U.S. Energy Information Administration (EIA),¹¹ the estimated total storage capacity of LNG peakshaving and satellite facilities in the Lower 48 States as of mid-2001 is 86 billion cubic feet (Bcf). LNG peakshaving and satellite storage account

¹¹ U.S. EIA: *U.S. LNG Markets and Uses*, January 2003.

for 80 percent of U.S. LNG storage capacity (see Figure 11), but it is only two percent of the total natural gas storage capability in the Lower 48. For example, in addition to LNG peakshaving 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. Despite the relatively low percentage of total gas storage capacity represented, the high daily deliverability of LNG facilities (see Figure 12) makes them an important source of fuel during winter cold snaps. LNG facilities can deliver up to about 11 Bcf/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.

Application of Safety Conditions to the LNG Value Chain

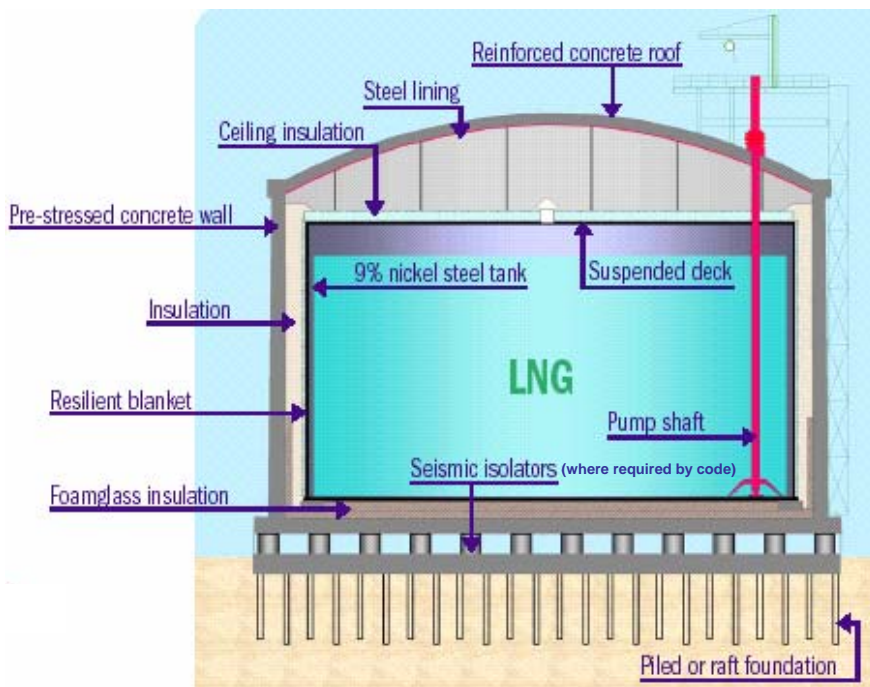
In this paper, we do not address risks and hazards associated with exploration and production activities, processing of natural gas or safety and security associated with natural gas pipeline or local gas utility distribution systems. The U.S. and other countries maintain health, safety, and environment (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.

Figure 13. Conceptual Design of Storage Tanks



Source: Shell

Several *engineering design* features ensure the safety of LNG storage tanks (see Figure 13). 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.

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 – it 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

pipings designs are through the roof of the tank to avoid siphoning of the full content of the tank in case of piping failures.

Figure 14. Single Containment Tanks



Source: Williams

A *single containment* tank (shown in Figure 14 at left) 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.

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 June 2003:



Source:

- Spherical (Moss) design account for 52 percent of the existing ships,
- Membrane design account for about 46 percent, and
- Self-supporting structural prismatic design account for about 2 percent.

Figure 15. A Spherical Tank

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

Figure 16. LNG Lagos - Membrane Type LNG Carrier



Source: NLNG

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.

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.¹² 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. peakshaving 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.

Figure 17. Double Containment Tanks



Source: ALNG

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.¹³ The majority of LNG storage tanks built recently around the world are designed as double or full containment tanks.



Source: CH-IV International

Figure 18. Full Containment Tanks

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

12 British Standards Institution (BSI) BS 7777: 1993 Parts 1: <http://www.hse.gov.uk/hid/land/comah/level3/5C39A0F.HTM>.

13 British Standards Institution (BSI) BS 7777: 1993 Parts 1: <http://www.hse.gov.uk/hid/land/comah/level3/5C39A0F.HTM>.

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.¹⁴ The tanks are designed in accordance with international LNG codes (EMMUA 147,¹⁵ 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 proposed a full containment LNG tank system for the new LNG terminal in Hackberry, Louisiana.

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.

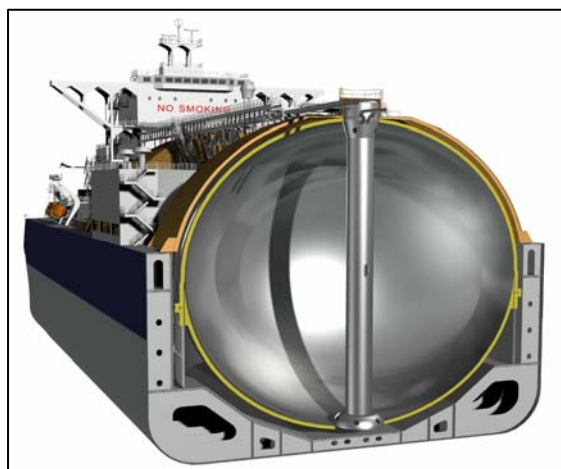


Figure 19. Tank Section of a Spherical Moss Design

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

14 British Standards Institution (BSI) BS 7777: 1993 Parts 1:
<http://www.hse.gov.uk/hid/land/comah/level3/5C39A0F.HTM>.

15 U.K. Engineering Equipment and Materials Users Association (EEMUA), 1986,
<http://www.hse.gov.uk/hid/land/comah/level3/5C85DD9.HTM>.

evaporates (see Figure 19). Materials used to construct the secondary barrier include aluminum or stainless steel foil, stainless steel and invar.

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 shut down systems can be activated upon detection of leaks, spills, or gas vapors. While there are different types of designs for LNG facilities, health, safety and environmental (HSE) considerations are generally similar. Various codes and standards (see Industry Standards and Regulation section) 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 193.¹⁶ 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.¹⁷ 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 Research Institute (GRI) 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

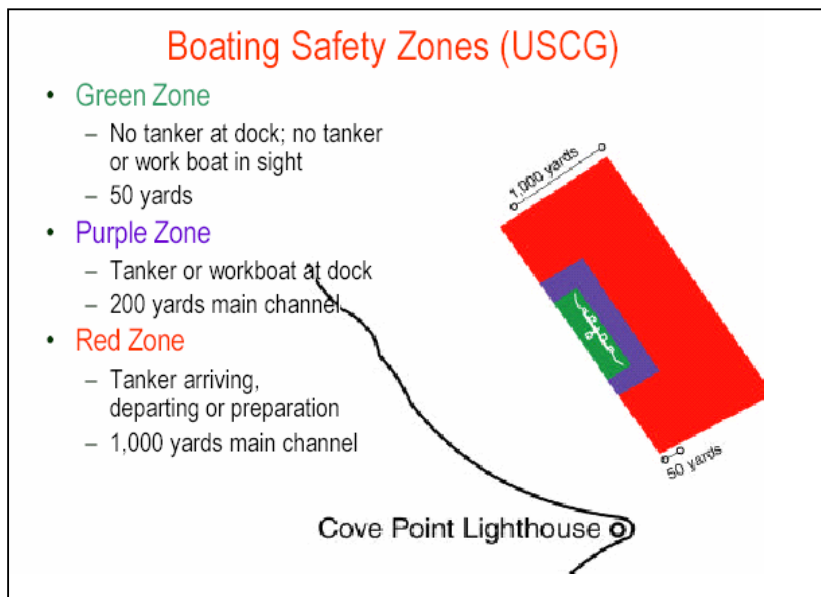
¹⁶ 49 CFR Part 193: <http://cfr.law.cornell.edu/cfr/cfr.php?title=49&type=part&value=193>.

¹⁷ 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.

Figure 20. Safety Zone at Cove Point



Source: Williams

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.

INDUSTRY STANDARDS/REGULATORY COMPLIANCE

In the U.S., several *regulatory authorities* govern the LNG industry. The U.S. Department of Energy–Office of Fossil Energy¹⁸ helps to coordinate across federal agencies that have regulatory and policy authority for LNG. The U.S. Federal Energy Regulatory Commission (FERC)¹⁹ 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.²⁰ The U.S. Department of Transportation (DOT)²¹ regulates offshore receiving terminals and operations.

The U.S. Environmental Protection Agency (EPA)²² 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,²³ Army Corps of Engineers²⁴ (for coastal facilities and wetlands), Minerals Management Service²⁵ (for offshore activities), National Oceanic and Atmospheric Administration²⁶ (for any activities near marine sanctuaries), and Department of Labor Occupational Safety & Health Administration (OSHA)²⁷ for LNG workplace protections. These agencies, as well as DOT, USCG, and FERC, all have authority over comparable activities for industries other than LNG.

¹⁸ U.S. Department of Energy – Office of Fossil Energy: <http://www.fe.doe.gov/>.

¹⁹ U.S. Federal Energy Regulatory Commission (FERC): <http://www.ferc.fed.us/>.

²⁰ U.S. Coast Guard (USCG): <http://www.uscg.mil/uscg.shtm>.

²¹ U.S. Department of Transportation (DOT): <http://www.dot.gov/>.

²² U.S. Environmental Protection Agency (EPA): <http://www.epa.gov/>.

²³ U.S. Fish and Wildlife Service: <http://www.fws.gov/>.

²⁴ U.S. Army Corps of Engineers: <http://www.usace.army.mil/>.

²⁵ U.S. Minerals Management Service: <http://www.mms.gov/>.

²⁶ U.S. National Oceanic and Atmospheric Administration: <http://www.noaa.gov/>.

²⁷ 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 4 discusses in 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).²⁸ The following regulations and standards/codes provide guidelines for the design, construction and operation of LNG facilities. See Appendix 3 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 59A²⁹ *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*

²⁸ U.S. Code of Federal Regulations: <http://www.access.gpo.gov/nara/cfr/index.html>.

²⁹ 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 7777³⁰ in 1996.
- EN 1160 – *Installation and equipment for Liquefied Natural Gas – General Characteristics of Liquefied Natural Gas.*
- EEMUA 147³¹ - *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.*

³⁰ British Standards Institution (BSI) BS 7777:
<http://www.hse.gov.uk/hid/land/comah/level3/5C39A0F.HTM>.

³¹ U.K. Engineering Equipment and Materials Users Association (EEMUA)
<http://www.hse.gov.uk/hid/land/comah/level3/5C85DD9.HTM>, 1986

- 33 CFR 165.30 *Regulated Navigation Areas and Limited Access Area: Security Zones*.

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 (CO₂) and toxic, heavy metals.³² 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 (SO₂) 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 SO₂ emissions are virtually eliminated and CO₂ emissions are reduced significantly compared to other fuels such as coal and fuel oil, which require scrubbing or other technologies to remove SO₂ or carbon reduction strategies such as sequestration to deal with CO₂.

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.

³² New York Energy Planning Board, *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.

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)*³³ 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 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 will 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.³⁴ 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).

³³ International Maritime Organization (IMO) <http://www.imo.org>.

³⁴ Sember, W.J. ABS: Development of Guidelines for Classification of Offshore LNG Terminals, GASTECH 2002, Qatar, Oct. 2002.

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

As of Sept. 2003, the global LNG industry comprises 17 export (liquefaction) facilities, 40 receiving (re-gasification) terminals, and 145 ships, altogether handling more than 110 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 40,000 LNG ship voyages, covering more than 60 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.³⁵ Appendix 5 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

³⁵ Phil Bainbridge, VP BP Global LNG, *LNG in North America and the Global Context*, IELE/AIPN Meeting University of Houston, October 2002.

fatalities, which compares favorably with the safety record of facilities for competing fuels.”³⁶ 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 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.

Future publications of the CEE mentioned in this paper and the complete *Guide to LNG in North America* will provide extensive information to those interested in U.S. energy trends and security; LNG industry and market developments. The CEE web site, <http://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.

³⁶ New York Energy Planning Board, *Report on issues regarding the existing New York Liquefied Natural Gas Moratorium*, November 1998.

Appendix 1: LNG Frequently Asked Questions³⁷

What is LNG?

Liquefied Natural Gas (LNG) is natural gas cooled to a liquid state. When natural gas is cooled to a temperature of approximately -256°F at atmospheric pressure, it condenses to a liquid. To liquefy natural gas, impurities that would freeze, such as water, carbon dioxide, sulfur, and some of the heavier hydrocarbons are removed. The volume of this liquid takes up about 1/600th of the volume of natural gas at a stove burner tip. LNG weighs about 45 percent as much as water and is odorless, colorless, non-corrosive, and non-toxic.

What is the history of LNG?

The liquefaction of natural gas dates back to the early 1900s. The first practical compressor refrigeration machine was built in Munich in 1873. The first LNG facility was built in West Virginia in 1912 and began operation in 1917. The first commercial liquefaction facility was built in Cleveland, Ohio, in 1941. In January 1959, the world's first LNG tanker, *The Methane Pioneer*, a converted World War II liberty freighter containing five, 7000 Bbl aluminum prismatic tanks with balsa wood supports and insulation of plywood and urethane, carried an LNG cargo from Lake Charles, Louisiana to Canvey Island, United Kingdom. This event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean. LNG has also been used as a vehicle fuel since the mid 1960s.

³⁷ Sources of the materials used in this section include:

1. Department of Energy, Alternative Fuels Data Center, http://www.afdc.doe.gov/altfuel/natural_gas.html.
2. Applied LNG Technologies, http://www.altlngusa.com/ngf_lng.htm.
3. Australia LNG, <http://www.australialng.com.au/>.
4. BG Group, http://www.bg-group.com/group/LNG_2001.htm.
5. BP LNG, <http://www.bp LNG.com/>.
6. CH-IV, <http://www.ch-iv.com/lng/lngfact.htm>.
7. Chive Fuels, <http://www.lng-cng.com/chivefuels/liquefiednaturalgas.htm>.
8. Crystal Energy, LLC, <http://www.crystalenergyllc.com/index.html>.
9. Dominion Cove Point, LNG, <http://www.dom.com/about/gas-transmission/covepoint/faq.jsp>.
10. El Paso, http://www.elpaso.com/business/LNG_FAQ.shtm.
11. North Star Industries, <http://northstarind.com/lngfaqs.html>.
12. Ras Laffan Industrial City, <http://www.qp.com.qa/raslaffan/rlc.nsf/web/introlngfacts#>.
13. Federal Energy Regulatory Commission (FERC), <http://www.ferc.gov/for-citizens/lng.asp>.

What is the composition of LNG?

Natural gas is composed primarily of methane (typically, at least 90 percent), but may also contain ethane, propane and heavier hydrocarbons and small quantities of nitrogen, oxygen, carbon dioxide, sulfur compounds, and water. The liquefaction process that produces LNG removes any oxygen, carbon dioxide, sulfur compounds, and water.

Where does LNG come from?

LNG supplies come primarily from locations where large gas discoveries have been made and countries that produce a lot of gas associated with oil fields, such as Algeria, Trinidad, Nigeria, Indonesia, Qatar, Oman, Malaysia, Libya, Abu Dhabi, Brunei and Australia. Some LNG is produced in Alaska as well.

Can difference between foreign LNG and U.S. pipeline gas cause any problem?

Foreign LNG sometimes has a higher heating value than typical U.S. pipeline natural gas. However, LNG terminal operators measure heating values and respond with a number of techniques, such as blending, dilution, or adding an inert component, which insures compatibility with U.S. pipeline gas. The fact that foreign LNG has been imported for over 25 years into Boston and Lake Charles and then mixed into the U.S. pipeline network without incident proves that this is not a significant safety issue.

Why liquefy natural gas?

Converting natural gas to a liquid reduces its volume by about 600 to 1. Liquefying natural gas makes it feasible to transport natural gas by tanker and to store it in preparation for re-gasification and delivery to markets.

How is natural gas liquefied?

A large refrigeration system liquefies natural gas by cooling it to -256 degrees Fahrenheit.

How many LNG facilities are there in the U.S.?

There are 113 active LNG facilities in the U.S.. Natural gas is liquefied and stored at about 58 facilities in 25 states and 96 LNG storage facilities are connected to the natural gas pipeline grid. Massachusetts alone accounts for 14 major satellite facilities, or roughly 40 percent of all satellite facilities in the United States. There are five satellite LNG facilities in New Jersey, the second highest in the U.S.. There are currently over 200 peakshaving and LNG storage facilities worldwide, some operating since the mid-1960s.

How is LNG used?

LNG is used worldwide for established, as well as emerging applications:

- World Trade. Natural gas is liquefied and transported by ship from remote reserves to markets in Asia, Europe and North America, where it is often used to fuel electric power facilities. Growing needs for electricity in Asia have increased demand for LNG nearly 8 percent per year since 1980, making it one of the fastest growing energy sectors.
- Seasonal Gas Storage. Roughly 100 LNG facilities, called peakshaving facilities, have been constructed worldwide to liquefy and store natural gas during warmer months for vaporization and injection into local pipelines during cold weather.
- Alternative Motor Fuel to Diesel. With only one carbon and four hydrogen atoms per molecule, methane is the cleanest burning fossil fuel. In liquid form, much more fuel can be stored aboard vehicles than as compressed natural gas (CNG) so it is well suited for high-fuel-consumption vehicles.

What are the advantages of LNG?

- LNG takes up 600 times less space than regular natural gas at ambient temperature and pressure, which makes it easier to transport and store than natural gas. LNG can be stored above or below ground in specially designed double walled storage tanks.
- LNG can be transported over long distances via double-hulled LNG ships, which are specially designed tankers that keep the LNG chilled during transport.
- LNG is replacing diesel in many heavy-duty trucks and buses and many new gas-fueled locomotives as a lower emissions alternative.

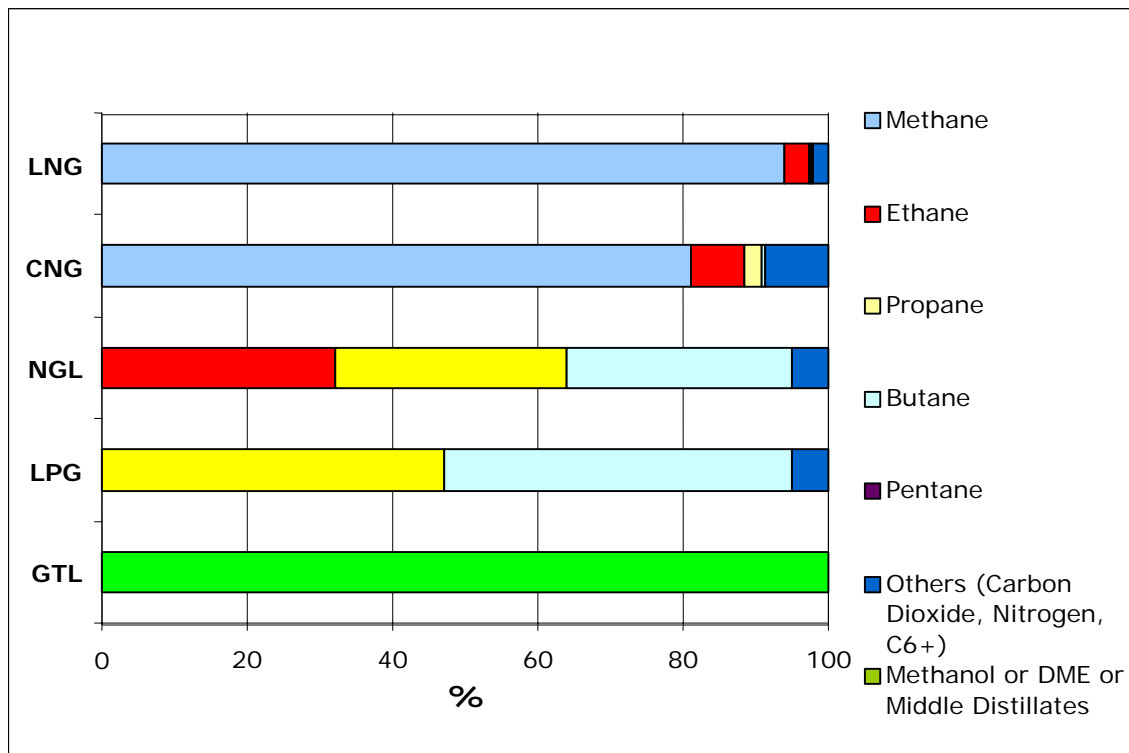
What are the disadvantages of LNG?

- LNG operations are capital intensive. Upfront costs are large for construction of liquefaction facilities, purchasing specially designed LNG ships, and building re-gasification facilities.
- Methane, a primary component of LNG, is considered a greenhouse gas because it increases carbon levels in the atmosphere when released.

What is the difference between LNG, CNG, NGL, LPG, and GTL?

It is important to understand the difference between Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Natural Gas Liquids (NGL), Liquefied Petroleum Gas (LPG), and Gas to Liquids (GTL). Figure 21 shows the difference in typical composition of these products.

Figure 21. Typical Composition of LNG, NGLs, CNG, GTL, and LPG



LNG is made up of mostly methane. The liquefaction process requires the removal of the non-methane components like carbon dioxide, water, butane, pentane and heavier components from the produced natural gas. CNG is natural gas that is pressurized and stored in welding bottle-like tanks at pressures up to 3,600 psig. Typically, CNG is the same composition as pipeline quality natural gas. NGLs are

made up mostly of molecules that are heavier than methane like ethane, propane, butane. LPG is a mixture of propane and butane in a liquid state at room temperatures. GTL refers to the conversion of natural gas to products like methanol, dimethyl ether (DME), middle distillates (diesel and jet fuel), specialty chemicals and waxes.

Who regulates LNG industry in the U.S.?

In the U.S., the LNG industry is governed by federal, state and local agencies.

Federal agencies include:

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

How does LNG benefit the United States?

LNG supplements America's natural gas supply. Natural gas is the fuel of choice for the vast majority of new power facilities being built in the country today. Because of this demand, the domestic natural gas market is expected to grow from 22 trillion cubic feet to 30 trillion cubic feet within the next 10 years. To help meet that growing demand, LNG will play an increasingly larger role in the country's energy supply mix.

How is LNG transported for export?

LNG is transported in specially designed ships to re-gasification facilities. These ships are double-hulled and have capacities from 25,000 to 138,000 m³ or more. The ships are fitted with a special cargo containment system inside the inner hull to maintain the LNG at atmospheric pressure and -256°F. There are about 145 ships currently in the global LNG fleet and more than 56 additional ones are on order.

What facilities make up an LNG import terminal?

An LNG import terminal consists of berths for mooring ships to discharge LNG onshore via pipelines, LNG storage tanks, vaporizers, to turn LNG from a liquid back into natural gas, and utilities for operating the facility.

How is LNG stored?

LNG is stored in tanks designed to contain the product safely and securely. Storage tank designs vary. Large tanks are low aspect ratio (height to width) and cylindrical in design with a domed roof. LNG is stored at atmospheric pressure. LNG must be maintained cold to remain a liquid, independent of pressure.

How is LNG kept cold?

Insulation, as efficient as it is, will not keep the temperature of LNG cold by itself. LNG is stored as a *boiling cryogen* -- a very cold liquid at its boiling point given the pressure at which it is being stored. Stored LNG is analogous to boiling water, only 472°F colder. The temperature of boiling water (212°F) does not change, even with increased heat, as it is cooled by evaporation (steam generation). In much the same way, LNG will stay at near constant temperature if kept at constant pressure. This phenomenon is called *autorefrigeration*. As long as the steam (LNG boil off vapor) is allowed to leave the tea kettle (tank), the temperature will remain constant. This boil off is captured by the LNG facilities and ships and used as fuel or sent to the pipeline grid.

What are the regulatory requirements for LNG ships?

LNG ships must comply with relevant local and international regulatory requirements including those of the International Maritime Organization (IMO), International Gas Code (IGC) and the USCG. All LNG ships must also comply with host Port Authority requirements. Specific regulations are outlined in Appendix 3.

Is LNG safe?

LNG has been safely handled for many years. The industry has maintained an excellent safety record, especially over the past 40 years. The safe and environmentally sound operation of these facilities, both ships and terminals, and the protection of these facilities – like other critical parts of the energy

infrastructure -- from terrorist activities or other incidents are a concern and responsibility shared by operators as well as federal, state and local authorities across the U.S. Onshore LNG facilities are industrial sites and, as such, are subject to all rules, regulations and environmental standards imposed by the various jurisdictions. These same or similar concerns apply to natural gas storage, pipeline transportation, distribution and consumption of natural gas.

Have there been any serious LNG accidents?

LNG is a form of energy and must be understood as such. Today LNG is transported and stored as safely as any other liquid fuel. In 1944, before the storage of cryogenic liquids was fully understood, however, there was a serious incident involving LNG in Cleveland, Ohio. This incident virtually stopped all development of the U.S. LNG industry for 20 years.

In addition to Cleveland, there are other U.S. incidents sometimes attributed to LNG. A construction accident on Staten Island in 1973 has been cited by some parties as an "LNG accident" because the construction crew was working inside an empty LNG tank. In another case, the failure of an electrical seal on an LNG pump in 1979 permitted gas (not LNG) to enter an enclosed building. A spark of indeterminate origin caused the building to explode. As a result of this incident, the electrical code has been revised for the design of electrical seals used with all flammable fluids under pressure.

How does an LNG fire compare with other fuel fires?

Fighting an LNG spill fire is very similar to fighting any hydrocarbon fire. Techniques have been refined over the years to cope with LNG as with any other hydrocarbon fire. The Texas A&M fire school and Northeast Gas Association have been training fire fighters and other industry professionals on LNG spill fires for over 25 years. Development of special dry chemical and high expansion foam systems to control LNG fires began with a series of industry sponsored tests and

resulted in engineering data that permit the LNG facility designer to configure very reliable LNG fire control systems.^{38, 39}

Will LNG burn?

LNG vapor, mainly methane (natural gas), burns only within the narrow range of a 5 percent to 15 percent gas-to-air mixture. If the fuel concentration is lower than 5 percent, it cannot burn because of insufficient fuel. If the fuel concentration is higher than 15 percent, it cannot burn because there is insufficient oxygen. For LNG to burn, it must be released, vaporize, mix with air in the flammable ratio, and be exposed to an ignition source. From an environmental standpoint there is very little smoke associated with an LNG fire.

Will LNG explode?

Explosion is a hazard unlikely to occur with LNG activity. LNG in liquid form itself will not explode within storage tanks, since it is stored approximately -256°F (-160°C) and at atmospheric pressure. Without pressure or confinement or heavily obstructed clouds of the vapors, there can be no explosion. An explosion from a release of LNG vapors is possible only if all the following conditions occur at the same time: vapors are in the flammability range, vapors are in a confined space and a source of ignition is present.

Is an LNG spill detectable?

Within an LNG facility or onboard a ship, there are various types of detectors used to alert personnel to a leak or spill. These could include detectors for the presence of gas, flame, smoke, high temperatures or low temperatures. While LNG vapors have no odor or color, if an LNG release occurs, LNG's low temperature causes water vapor to condense in the air and form a highly visible white cloud.

³⁸ H. H. West, L.E. Brown and J.R. Welker, Vapor Dispersion, Fire Control, and Fire Extinguishment for LNG Spills, Proceedings of the Spring Technical Meeting of the Combustion Institute, San Antonio (1975).

³⁹ Fire Protection Handbook, Volume II, Gulf Publishing, Houston (1983).

Would an LNG spill mean similar pollution to an oil spill?

If LNG were to leak, it would quickly evaporate leaving no residue when it came into contact with soil or water; so there is no need for environmental clean up of LNG spills on water or land.

How are LNG terminals designed to be safe?

Safety features include gas detectors, ultraviolet or infrared (UV/IR) fire detectors, closed-circuit TV, offsite monitoring, personnel training requirements, and restricted access to terminal property. In addition, the stringent design parameters for LNG import terminals require that proper measures are in place in the unlikely event of a spill or equipment failure.

What are the public safety issues related to LNG?

Flammable Vapor Clouds

- If LNG is released, the resulting LNG vapors (methane) will warm, become lighter than air, and disperse with the prevailing wind. Cold LNG vapor will appear as a white cloud.
- If a source of ignition is present where LNG vapors (methane) exist at a 5%-to-15% concentration in the air, the vapor cloud will burn along a flame front toward the source of the fuel.
- It should also be noted that LNG vapors do not catch fire as easily as those of other common fuels such as gasoline or propane, and LNG vapors dissipate more easily, meaning that potential hazards can persist longer for other fuels than for LNG.

Fires

- If LNG is released in the presence of an ignition source, a fire will result from the continuous evaporation of the LNG contained within the impoundment.
- Since this fire would burn with intense heat, firefighting and other safety equipment is installed at terminals and onboard ships to help manage an incident.

- "Liquefied Natural Gas Facilities: Federal Safety Standards" are found in Title 49 CFR Part 193.

How are LNG ships designed to be safe?

LNG ships are especially designed with a double hull to provide optimum protection for the integrity of the cargo in the even of collision or grounding. The ship has 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, nitrogen purging, double hulls and double containment tanks or leak pans. Should fire occur on the ship, two 100 % safety relief valves on each tank 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.

Aside from design features, are there additional safety measures for LNG ships?

To ensure safety for transportation of LNG, the USCG requires safety zones around LNG ships. The safety zones prohibit entry by other ships thereby helping to eliminate the possibility of a collision of an LNG ship with another ship. In fact, the concept of a safety zone is not confined to shipping. Like the safety zones applied in operating aircraft, and even our cars, LNG safety zones allow a safe stopping

distance in the event that another ship loses control. A USCG escort boat manages the safety zone around a ship. The USCG uses safety zones to centrally manage and coordinate shipping traffic in coordination with port authorities. Through the use of strict operational procedures, putting a priority on safety and well-trained, well-managed crews, shipping risks are well managed.

Is LNG environmentally friendly?

When LNG is vaporized and used as fuel, it reduces particle emissions to near zero and carbon dioxide (CO₂) emissions by 70 percent in comparison with heavier hydrocarbon fuels. When burned for power generation, the results are even more dramatic. Sulfur dioxide (SO₂) emissions are virtually eliminated and CO₂ emissions are reduced significantly. If spilled on water or land, LNG will not mix with the water or soil, but evaporates and dissipates into the air leaving no residue. It does not dissociate or react as does other hydrocarbon gases and is not considered an emission source. Additionally there are significant benefits when natural gas is used as fuel over other fossil fuels. However, methane, a primary component of LNG, is considered to be a greenhouse gas and may add to the global climate change problem if released into the atmosphere.

What happens if there is an LNG release at the storage facility?

An LNG release is very unlikely due to the strict design requirements for facilities. The design of LNG tanks and piping prevents releases or spills. But if there is a rupture of a segment of piping in the facility, a spill of LNG could occur. The facility is designed so that such a spill would be contained. Liquid would accumulate in one of several catch basins, where it would evaporate. Emergency shutdown systems would be involved to minimize any release. The tank impoundment in the facility can contain more than 100 percent of the LNG tank volume, which assures that the release from any accident will be fully contained. The rate of evaporation and the amount of vapors generated are dependent on the amount of liquid spilled and the surface area of the catch basin.

How are the LNG facilities designed to be safe?

All facilities that handle LNG have built-in systems to contain LNG and prevent fires. This is true whether in the LNG facility, transferring LNG to and from LNG ships, shipping LNG or vaporizing (re-gasifying) LNG. There are differences in design among these types of facilities, but the environmental, health and safety issues are the same.

Appendix 2: 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.

Figure 22. LNG Jetty with Unloading Arms - ALNG



Source: Phillips66

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 22 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 could enable offshore LNG storage and re-gasification. **Offshore LNG receiving facilities** have not yet been built, but engineering and economic feasibility are under development in the U.S. and elsewhere. The various proposals for offshore LNG receiving facilities in the U.S. include: 1) Port Pelican, proposed by ChevronTexaco, to be located off the southwestern Louisiana coastline; 2) a conversion of an existing offshore oil and gas platform proposed by Crystal Energy

that is located 11 miles from Ventura County, California into an LNG receiving/re-gasification terminal; 3) BHP Billiton Cabrillo Deepwater Port, a Floating Storage and Re-gasification Unit (FSRU) off the California coast, approximately 21 miles offshore Port Hueneme and 4) Energy Bridge, a modified LNG tanker/re-gasification/subsea buoy system developed by El Paso Energy Corporation (which also has an initial permit filing for offshore Louisiana). The USCG currently is developing necessary regulations for these kinds of facilities.

Research and development is also being conducted on the feasibility of offloading and storing LNG in **salt caverns**, which would eliminate the need for storage tanks.⁴⁰

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 m³ to 160,000m³). In Japan, Osaka Gas is building the world's largest above-ground tank (180,000m³), 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*).

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.

⁴⁰Department of Energy, Office of Fossil Energy:
http://www.fossil.energy.gov/news/techlines/03/tl_lngsaltstorage.html

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 m³. There are 61 in-ground storage tanks in Japan.



Source: www.takenaka.co.jp

Figure 23. Underground LNG tank: T-2 tank at Fukukita station of Saibu Gas Co., Ltd.

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 24. In pit LNG storage tank



Source: SIGTTO

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 24 for an example of an in pit LNG storage tank.

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).

Figure 25. Open Rack Vaporizer



Source: www.spp.co.jp

Open Rack Vaporizer (ORV) (shown in Figure 25) uses seawater as its 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. ORV has the following special features:

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

Figure 26. Seven Submerged Combustion Vaporizers, Lake Charles, La., Terminal



Source: www.cmspanhandlecompanies.com

Submerged Combustion Vaporizer (SCV) uses hot water heated by the submerged combustion burner to vaporize LNG in the stainless tube heat exchanger. SCV (shown in Figure 26) is applied mainly to the vaporizer for emergency or peakshaving operation, but it is also used as a baseload. SCV has following special features:

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

Appendix 3: 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).⁴¹ 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.

⁴¹ 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.

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 7777⁴² 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 147⁴³ - *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

⁴²British Standards Institution (BSI) BS 7777 : <http://www.hse.gov.uk/hid/land/comah/level3/5C39A0F.HTM>

⁴³ U.K. Engineering Equipment and Materials Users Association (EEMUA) <http://www.hse.gov.uk/hid/land/comah/level3/5C85DD9.HTM>, 1986

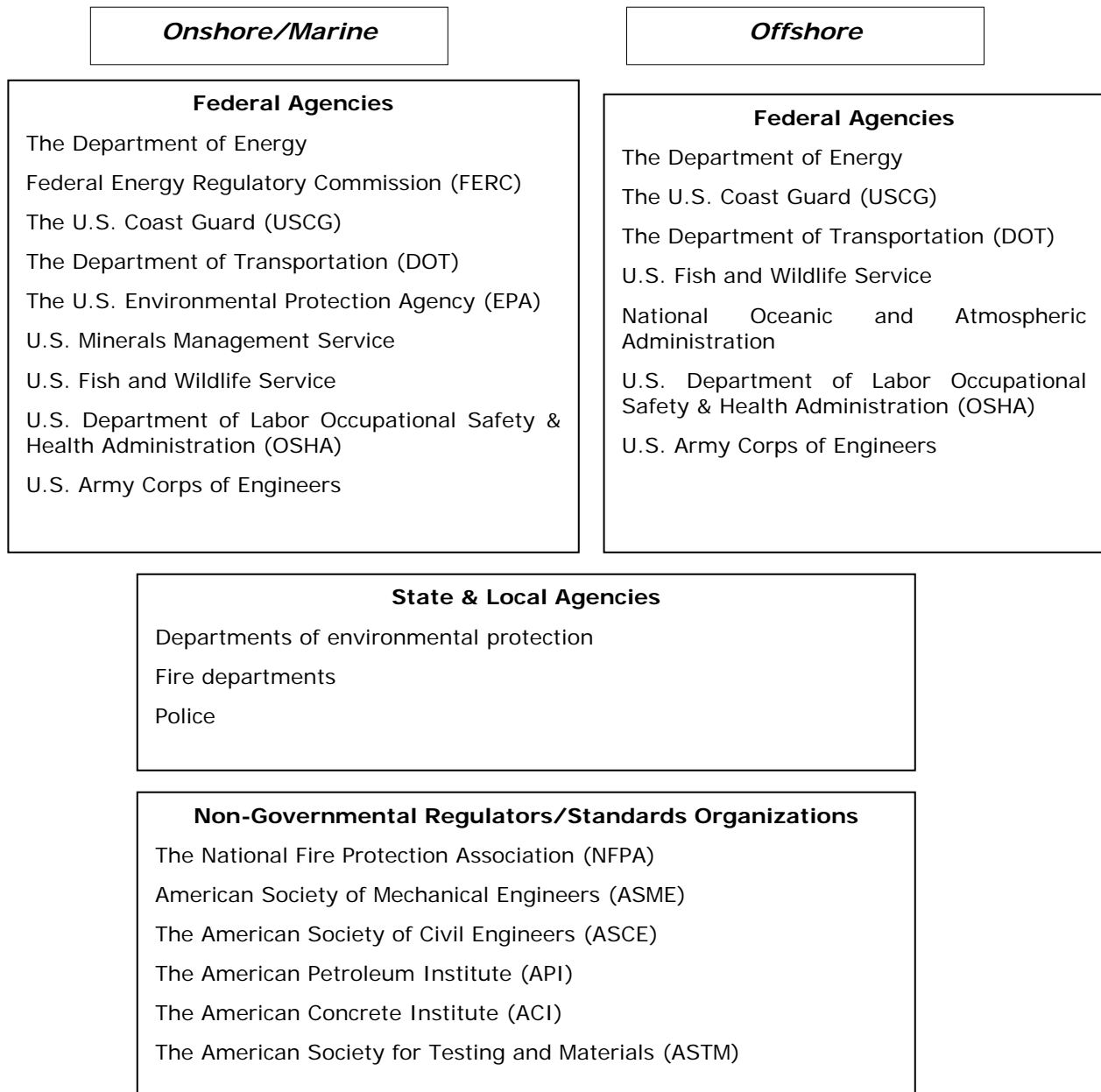
carrying flammable or toxic cargoes, fireworks barges, long tows by tugs, or events like high speed races.

- 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 4: 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 27.

Figure 27. U.S. LNG Regulators



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. FERC has jurisdiction over onshore import and export facilities, and some peakshaving facilities, and thus, regulatory control over most of existing U.S. LNG facilities. FERC has significant oversight responsibility for LNG import and export facilities during their

construction. 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.

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, 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)⁴⁴, the American Society of Civil Engineers (ASCE)⁴⁵, the American Petroleum Institute (API)⁴⁶, the American Concrete Institute (ACI)⁴⁷, and the American Society for Testing and Materials (ASTM)⁴⁸. (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.

⁴⁴ American Society of Mechanical Engineers (ASME) <http://www.asme.org/>

⁴⁵ American Society of Civil Engineers (ASCE) <http://www.asce.org/>

⁴⁶ American Petroleum Institute (API) <http://api-ec.api.org>

⁴⁷ American Concrete Institute (ACI) <http://www.aci-int.org/>

⁴⁸ American Society for Testing and Materials (ASTM) <http://www.astm.org>

Appendix 5: 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 codes⁴⁹ 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."⁵⁰

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

⁴⁹ 49 CFR Part 193: <http://cfr.law.cornell.edu/cfr/cfr.php?title=49&type=part&value=193>

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

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.

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. The CEE has a separate case study on Japan's long experience with LNG and safety record.⁵¹

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

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

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 40,000 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.

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

⁵¹ Contact the CEE for details and availability.

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 6: Major LNG Incidents⁵²

According to the U.S. Department of Energy,⁵³ 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. H.H. West and M.S. Mannan of Texas A&M University⁵⁴ 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 peakshaving facility was built in West Virginia. In 1941, the East Ohio Gas Company built a second facility in Cleveland. The peakshaving 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 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

⁵² Much of the materials in this section are taken West, H.H. and Mannan, M.S. 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.

⁵³ Juckett, Don, U.S. Department of Energy, *Properties of LNG*. LNG Workshop, MD, 2002.

⁵⁴ West, H.H. and Mannan, M.S. Texas A&M University: *LNG Safety Practice & Regulation: From 1944 East Ohio Tragedy to Today's Safety Record*, AIChE meeting, April 2001.

Mines, concluded that the concept of liquefying and storing LNG was still valid if "proper precautions were observed."⁵⁵

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 peakshaving 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 1973⁵⁶ 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."⁵⁷

Cove Point, Maryland, October 1979⁵⁸

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

⁵⁵ 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.

⁵⁶ Fire Department of the City of New York, *Report of Texas Eastern LNG Tank Fatal Fire and Roof Collapse, February 10, 1973*, July 1973.

⁵⁷ New York Energy Planning Board, *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.

⁵⁸ The content in this section is taken from CH-IV International Report *Safety History of International LNG Operations*, June 2002.

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 Board⁵⁹ 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 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

⁵⁹ National Transportation Safety Board Report, *Columbia LNG Corporation Explosion and Fire; Cove Point, MD; October 6, 1979*, NTSB-PAR-80-2, April 16, 1980.

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 4. Major LNG Incidents⁶⁰

Incident Date	Ship / Facility Name	Location	Ship Status	Injuries/ Fatalities	Ship/ Property Damage	LNG Spill/ Release	Comment
1944	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 Verne		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

⁶⁰ 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
							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.
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.

Incident Date	Ship / Facility Name	Location	Ship Status	Injuries/ Fatalities	Ship/ Property Damage	LNG Spill/ Release	Comment
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.

Appendix 7: Glossary of Terms^{61,62}

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
Peakshaving 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 peakshaving 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.
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.

⁶¹ Phillips Petroleum Company, <http://www.phillips66.com/lng/LNGglossary.htm>.

⁶² Poten & Partners, http://www.poten.com/?URL=ut_glossary.asp.

Appendix 8: Conversion Table

Natural gas and LNG	To		million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
	billion cubic metres NG	billion cubic feet NG				
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		kilolitres	barrels	U.S. gallons	tonnes/year
	tonnes (metric)	billion cubic metres NG				
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		kilolitres to tonnes	tonnes to barrels	tonnes to kilolitres
	barrels to tonnes	tonnes to barrels			
	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>.