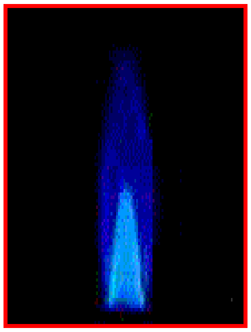
GROUPE INTERNATIONAL DES IMPORTATEURS DE GAZ NATUREL LIQUÉFIÉ

THE INTERNATIONAL GROUP OF LIQUEFIED NATURAL GAS IMPORTERS

LNG Information Paper No. 1



Basic Properties of LNG

GIIGNL's Technical Study Group has overseen the development of this Information Series of seven papers to provide factual information about Liquefied Natural Gas (LNG). In French, Spanish, Portuguese, or Italian speaking countries, the abbreviation GNL is used in place of LNG. This paper begins with a review of Basic LNG properties, which is a pre-requisite for accurately assessing potential LNG safety hazards and risks. For more information on these topics, additional references and weblinks are provided at the end of this paper.

Introduction:

A basic knowledge of LNG must begin with an examination of its chemical and physical properties. Chemical and physical properties are fundamental to understanding LNG correctly. The very properties which make LNG a good source of energy can also make it hazardous if not adequately contained. These properties determine how LNG behaves, affect our predictions about its behaviours, and influence how we assess and manage safety risks. Furthermore, to accurately understand and predict LNG behaviour, one must clearly distinguish its properties as a liquid from its properties as a gas or vapour.

The reader will note that discussions of the properties of LNG often contain ominous caveats like "depending upon its exact composition" because such specifics matter. It is inexact and inappropriate to make universal generalisations about LNG. It is especially important to be clear in thinking through how LNG would behave if accidentally or intentionally released (e.g., from a terrorist attack), because the outcome would be profoundly influenced by the actual situation and site-specific conditions.

Misunderstanding LNG is not uncommon and is often caused by confusion, incomplete, or inaccurate information about LNG properties. Since properties determine behaviour and influence how we manage potential safety hazards and risks, having an accurate understanding is key.

A number of LNG companies have made commitments to educate the general public about their product. For example, companies in Japan and South Korea have gone to great lengths to share information about their facilities with the local communities and to educate them about LNG. For example, Osaka Gas Company and Tokyo Gas Company have installed Gas Science Museums at each of their terminals; the first one opened in 1982. More than 50,000 children, among other visitors, tour the museums every year and are able to observe table-top demonstrations of LNG properties and behaviours.

LNG is natural gas which has been converted to liquid form for ease of storage or transport. LNG takes up about 1/600th of the volume of natural gas. Depending upon its exact composition, natural gas becomes a liquid at approximately -162°C (-259°F) at atmospheric pressure.

LNG's extremely low temperature makes it a cryogenic liquid. Generally, substances which are -100°C (-48°F or less) are considered cryogenic and involve special technologies for handling. In comparison, the coldest recorded natural temperatures on earth are -89.4°C (-129 °F) at the height of winter in Antarctica and the coldest reported temperature in a town was recorded in

Oymayakon (Sakha Republic) during Siberian winter (-71.2°C; -96.16 °F). To remain a liquid, LNG must be kept in containers which function like thermos bottles – they keep the cold in and the heat out. The cryogenic temperature of LNG means it will freeze any tissue (plant or animal) upon contact and can cause other materials to become brittle and lose their strength or functionality. This is why the selection of materials used to contain LNG is so important.

LNG is odourless, colourless, non-corrosive, non-flammable, and non-toxic. Natural gas in your home may have been liquefied at some point but was converted into its vapour form for your use. The reason the natural gas you use in your home has a smell is because an odorising substance is added to natural gas before it is sent into the distribution grid. This odour enables gas leaks to be detected more easily.

Key liquid and gas properties for LNG are:

- Chemical Composition,
- Boiling Point,
- Density and Specific Gravity,
- Flammability, and
- Ignition and Flame Temperatures.

These properties are listed on Material Safety Data Sheets (MSDS's). [Control Right click here to View MDSD.]

Chemical Composition:

Natural gas is a fossil fuel, meaning it has been created by organic material deposited and buried in the earth millions of years ago. Crude oil and natural gas constitute types of fossil fuel known as "hydrocarbons" because these fuels contain chemical combinations of hydrogen and carbon atoms. The chemical composition of natural gas is a function of the gas source and type of processing. It is a mixture of methane, ethane, propane and butane with small amounts of heavier hydrocarbons and some impurities, notably nitrogen and complex sulphur compounds and water, carbon dioxide and hydrogen sulphide which may exist in the feed gas but are removed before liquefaction. Methane is by far the major component, usually, though not always, over 85% by volume. **Table 1** displays the chemical compositions of the hydrocarbon compounds which make up natural gas, and the volume ranges in which they may be present in LNG. Pipeline natural gas may contain small amounts of water vapour.

LNG is often confused with liquefied petroleum gas (LPG), which in turn is often incorrectly identified as propane. In fact, LPG is a mixture of mainly propane and butane gases that exist in a liquid state at ambient temperatures

Table 1.Typical chemical composition of LNG (Source: Center for Energy Economics, www.beg.utexas.edu/energyecon/lng)

Chemical	Chemical Formula	Low	High
Methane	CH_4	87%	99%
Ethane	C_2H_6	<1%	10%
Propane	C_2H_8	>1%	5%
Butane	C_4H_{10}	>1%	>1%
Nitrogen	N_2	0.1%	1%
Other Hydrocarbons	Various	Trace	Trace

when under moderate pressure (less than 1.5 MPa or 200 psi). In the U.S., Canada, and Japan, LPG consists primarily of propane (**Table 2**; next page). However, in many European countries, the propane content in LPG can be as low as 50% or less. Moreover, in some countries, LPG may contain a substantial portion of propylene.

LPG's differing composition and physical properties (from LNG) make its behaviour different as well. The propane and butane in LPG have different chemical compositions from methane, the primary hydrocarbon in natural gas and LNG. Propane and butane can be stored and transported as a mixture, or separately. Both are gases at normal room temperature and atmospheric pressure, like methane, readily vaporising. Propane liquefies much more easily than LNG (at -43°C [-46 °F] vs. -162°C [-259 °F] for LNG) so it is substantially easier to compress and carry in a portable tank. In fact, LPG is stored as a liquid under pressure at ambient (room) temperatures, whereas LNG is stored as a liquid only at very low temperatures and ambient pressure.

Boiling Point:

Boiling point is one of the most significant properties because it defines when gas becomes a liquid. Webster-Merriman on line (www.webster-merriman.com) defines "boiling point" as "the temperature at which a liquid boils" or at which it converts rapidly from a liquid to a vapour or gas at atmospheric pressure. The boiling point of pure water at atmospheric pressure is 100°C (212 °F). The boiling point of LNG varies with its basic composition, but typically is -162°C (-259 °F).

When cold LNG comes in contact with warmer air, water, or the environment, it begins to "boil" at that interface because the surrounding temperatures are warmer than the LNG's boiling point, as shown in **Figure 1.** **Table 3** shows the boiling points of water and common gases.

Table 2. Typical composition of LPG in % by volume (Source:http://www.environment.gov.au/settlements/transport/comparison/pub/2ch10.pdf)

Country	Propane	Butane
Belgium	50	50
France	35	65
Ireland	100*	100*
Italy	25	75
Germany	90	10
UK	100*	100*
Denmark	50	50
Greece	20	80
Netherlands	50	50
Spain	30	70
Sweden	95	5

*** NOTE**: In Ireland and the U.K., LPG may be 100% of either basic gas.

The liquefaction process cools natural gas to change it to a liquid which reduces the volume occupied by the gas by approximately 600 times. LNG is converted back into natural gas for distribution to industrial and residential consumers. The LNG regasification process warms the LNG and converts it back into its gaseous form.

Density and Specific Gravity:

Density is a measurement of mass per unit of volume and is an absolute quantity. Because LNG is not a pure substance, the density of LNG varies slightly with its actual composition. The density of LNG falls between 430 kg/m^3 and 470 kg/m^3 (3.5 to 4 lb/US gal). LNG is less than half the density of water; therefore, as a liquid, LNG will float if spilled on water.

Specific gravity is a relative quantity. The specific gravity of a liquid is the ratio of density of that liquid to density of water (at 15.6°C/60°F). The specific gravity of a gas is the ratio of the density of that gas to the density of air (at 15.6°C). Any gas with a specific gravity of less than 1.0 is lighter than air (buoyant). When specific gravity or relative density is significantly less than air, a gas will easily disperse in open or well-ventilated areas. On the other

Figure 1. LNG "boiling" at atmospheric pressure and temperature (Source: OSAKA Gas Co. Ltd.)

Table 3. Boiling points of water and some common gases (Source: Adapted from the Engineering Toolbox online, www.engineeringtoolbox.com/boiling-points-fluids-gases-d_155html)

Fahrenheit (degrees F)	Celsius (degrees C)	Occurrence
212	100	Water Boils
31	-0.5	Butane Boils
-27	-33	Ammonia Boils
-44	-42	Propane Boils
-259	***-162***	***LNG Boils***
-298	-183	Oxygen Boils
-319	-195	Nitrogen Boils
-422	-252	Hydrogen Boils
-454	-270	Helium Boils
-460	-273	Absolute Zero

NOTE: Absolute zero is the coldest temperature theoretically possible, and cannot be reached, by artificial or natural means. By international agreement, absolute zero is defined as precisely 0 K on the Kelvin scale and is equivalent to -273.15°C/-459.67 °F.

hand, any gas with a specific gravity of greater than 1.0 is heavier than air (negatively buoyant). The specific gravity of methane at ambient temperature is 0.554, therefore it is lighter than air and buoyant.

Under ambient conditions, LNG will become a vapour because there is no place on earth with a temperature of -162°C (-259 °F). As LNG vaporises, the cold vapours will condense the moisture in the air, often causing the formation of a white vapour cloud until the gas warms, dilutes, and disperses as shown in Figure 2.

Figure 2. LNG vapour cloud created for training at Texas A&M in the LNG Live Fire Training Workshop (2005) (Photograph by A.H. Walker)

For a relative humidity of higher than 55%, the flammable cloud is totally included in the visible vapour cloud. If the relative humidity is less than 55%, the flammable cloud can be partially or completely outside of the visible cloud, which means that the vapours could be ignited even though the ignition source is distant from the visible vapour cloud. The size of the vapour cloud will depend on wind speed, direction, and other weather conditions and can easily be predicted by the appropriate related calculations. These very cold vapours will rise as they are sufficiently warmed by ambient air.

LNG vapours at the boiling point temperature (-162°C/ -259 °F) and atmospheric pressure have a relative density of about 1.8, which means that when initially released, the LNG vapours are heavier than air and will remain near the ground. However as methane vapours begin to rapidly warm and reach temperatures around -110°C/-166 °F, the relative density of the natural gas will become less than 1 and the vapours become buoyant.

At ambient temperatures, natural gas has a specific gravity of about 0.6, which means that natural gas vapours are much lighter than air and will rise quickly. Cold LNG vapours (below -110°C/-166 °F) are negatively buoyant and more likely to accumulate in low areas until the vapours warm. Therefore, a release of LNG that occurs in an enclosed space or low spot will tend to replace the air (and oxygen) and make the area a hazard for breathing.

The rate of LNG vapour ascent depends upon the quantity of LNG released, ambient weather conditions, and where the LNG is released, e.g., confined or unconfined, low or elevated area, on land or on water. One strategy to manage the vapours is to create a downwind water curtain which helps block and/or divert the vapours away from possible ignition sources until the vapours warm and become buoyant, and/or dilute to a lesser concentration outside the flammable limits, which are discussed in the next section.

Heat input to LNG in any form will enhance vaporisation and dispersion. Such heat may be transferred from passive sources such as atmospheric humidity (which is a significant source), the ground or spill catchment areas, impoundments, pits and structures. LNG vaporises up to five times more quickly on water than on land, depending upon the soil condition. In fact, another strategy for managing the flammability hazard of LNG vapours is to use a water hose to warm the liquid more quickly (while avoiding contact with the super-cold LNG), increase vaporisation rates, and make the vapours buoyant sooner, rising away from ignition sources at ground level.

Flammability:

Flammability is the property which makes natural gas desirable as an energy source, and yet for the same reason flammability can be a safety hazard. It is very important to be clear: natural gas is flammable but LNG (the liquid form of natural gas) is not because of the lack of oxygen in the liquid. Since LNG begins vaporising immediately upon its release from a container, the important issue is when will the vapours be flammable and for how long?

Flammability Limits

Three things are needed to support a fire:

- A source of fuel (e.g., flammable gas or vapour),
- Air (oxygen), and
- A source of ignition (e.g., spark, open flame, or high-temperature surface).

This is known as the fire triangle (**Figure 3**). Several factors are required to start a fire from LNG vapours. In particular, the fuel and the oxygen have to be in a specific range of proportions to form a flammable mixture.

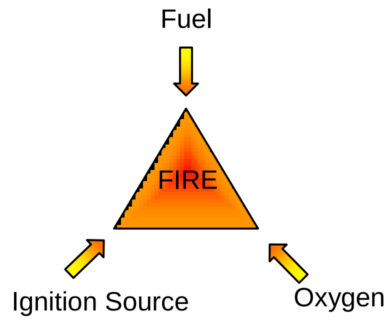


Figure 3. The fire triangle

This "Flammable Range" is the range of a concentration of a gas or vapour that will burn if an ignition source is introduced. The limits are commonly called the "Lower Flammable Limit" (LFL) and the "Upper Flammable Limit" (UFL) (**Figure 4**).

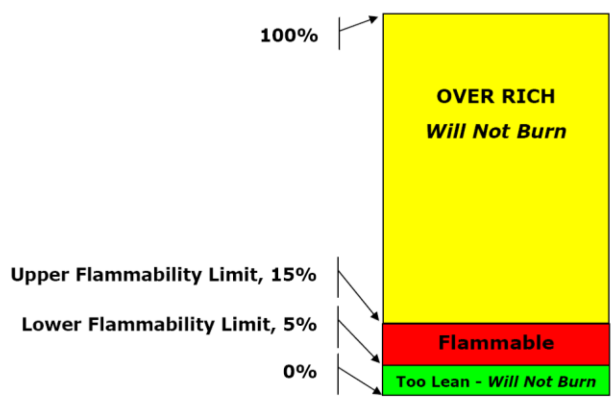


Figure 4. Flammability range for methane (Source: Foss 2003)

The LFL for methane is 5% and the UFL is 15% both by volume in air. Outside of this range, the methane/air mixture is not flammable. **Table 4** shows flammability limits for methane compared with other fuels. Many materials around us are flammable and it is important to be aware of each substance's flammability limits to assure safe handling and use. Materials that

Table 4. Flammability limits of hydrocarbon fuels (Source: NPFA Fire Protection Handbook)

Fuel	LFL	UFL
Methane	5.0	15.0
Butane	1.86	7.6
Kerosene	0.7	5.0
Propane	2.1	10.1
Hydrogen	4.0	75.0
Acetylene	2.5	>82.0

have wide flammable ranges make them dangerous to emergency responders because there is a longer time that they are within the flammable limits. For example, hydrogen and acetylene have a very wide range and Acetylene can burn whenever vapours are from just over 2% to over 80% in air.

In a closed storage tank or vessel, the percentage of methane is essentially 100% (mostly liquid and some vapours). Any small leak of LNG vapour from a tank in a well-ventilated area is likely to rapidly mix and quickly dissipate to lower than 5% methane in air. Because of the rapid mixing, only a small area near the leak would have the necessary concentration to allow the fuel to ignite. All LNG terminals use several types of equipment on and around the storage tanks and piping throughout the facility to detect any unlikely leakages and combustible gas mixtures. This safety equipment is described in Information Paper No. 6.

Ignition and Flame Temperatures

The ignition temperature, also known as auto-ignition temperature, is the lowest temperature at which a gas or vapour in air (e.g., natural gas) will ignite spontaneously without a spark or flame being present. This temperature depends on factors such as air-fuel mixture and pressure. In an air-fuel mixture of about 10% methane in air, the auto ignition temperature is approximately 540°C (1,000°F). Temperatures higher than the auto ignition temperature will cause ignition after a shorter exposure time to the high temperature. **Table 5** shows the auto-ignition temperature of some common fuels, indicating that diesel oil and gasoline will auto-ignite at substantially lower temperatures than LNG.

The precise auto ignition temperature of natural gas varies with its composition. If the concentration of heavier hydrocarbons in LNG increases (e.g., the methane portion

Table 5. Auto-ignition temperature of some fuels at standard conditions (Source: BV 2009)

	Natural Gas	Diesel Oil	Gasoline
Auto-ignition temperature	599°C	260-371°C	226-471°C

of the natural gas begins to evaporate or be removed from the mix), the auto ignition temperature decreases. In addition to ignition from exposure to heat, the vapours from LNG can be ignited immediately from the energy in a spark, open flame, or static electricity when they are within the flammable limits.

LNG has a very hot flame temperature. Simply stated it burns quickly and is a better heat source than other fuels, e.g., gasoline. The methane in LNG has a flame temperature of 1,330°C (2,426 °F). In comparison, gasoline has a flame temperature of 1,027°C (1,880 °F), which means LNG burns hotter. Also, LNG burns quickly, at a rate of about 12.5 m^2/minute, compared to gasoline's burn rate of 4 m^2/minute. LNG produces more heat when burning because its heat of combustion is 50.2 MJ/kg (21,600 Btu/lb), compared to that of gasoline which has a heat of combustion of 43.4 MJ/kg (18,720 Btu/lb). The combustion of LNG produces mainly carbon dioxide and water vapour. The radiant heat of an LNG fire is a frequent safety concern of government regulators and officials, and the public.

Key Points and Conclusions

In closing, the reader should remember the key points of this first information paper:

1. First, and most importantly, one must understand that the very properties which make LNG a good source of energy can also make it hazardous if not adequately contained. While LNG is predominately methane (about 87%-99%), its composition also includes small amounts other hydrocarbons. The specific chemical composition natural gas is a function of the gas source and type of processing. The chemical composition of the natural gas and the properties of its hydrocarbon components determine how LNG behaves, affect our predictions about its behaviours, and influence how we assess and manage safety risks. Misunderstanding LNG is not uncommon and is often caused by confusion, incomplete or inaccurate information about LNG properties. One also must clearly distinguish its properties as a liquid from its properties as a gas or vapour.

2. LNG, the liquid form of natural gas, is a fossil fuel, like crude oil other hydrocarbon-based forms of energy and products.

3. The “boiling point” of LNG is -162°C; -259 °F, which is considered a cryogenic temperature. At this temperature (somewhat depending upon its actual composition), LNG evaporates to convert from a liquid to a vapour.

4. Conversely, LNG becomes a liquid at these cryogenic temperatures (-162°C; -259 °F) at atmospheric pressure. As a liquid, it takes up about 1/600th the volume of natural gas. Consequently, it is generally transported and stored in a liquid state.

5. LNG is odourless, colourless, non-corrosive, non-flammable and non-toxic.

6. While natural gas is flammable, LNG is not. The flammability limits of methane are such that any small leak of LNG vapour from a tank in a well-ventilated area is likely to rapidly mix with air and quickly dissipate. Large leaks and spills are essentially precluded by a plethora of leak-detection systems and similar safeguards (which are discussed in later papers).

In summary, the basic properties and behaviours of LNG warrant that it be considered as a desirable option which can be managed safely when evaluating the mix of energy sources.

Next, in **Information Paper No. 2**, we will explore the “LNG Process Chain”. Subsequent papers in this series will include a discussion of the many ways in which LNG safety is assured, through Multiple Safety Layers, all firmly based on a foundation of solid Industry Standards, Regulatory Compliance and Codes. These “safety layers” include several key components of the industry’s Risk Management framework. Included among them are Primary and Secondary Containment, Control Systems which promote Operational Integrity; Protocols, Operator Knowledge and Experience (which are reinforced by comprehensive and ongoing training). A protective umbrella of Safeguard Systems, Separation Distances, and Contingency Planning further enhances safe management of LNG. A graphic illustration of these “Multiple Safety Layers” is reflected in the figure at the end of this paper.

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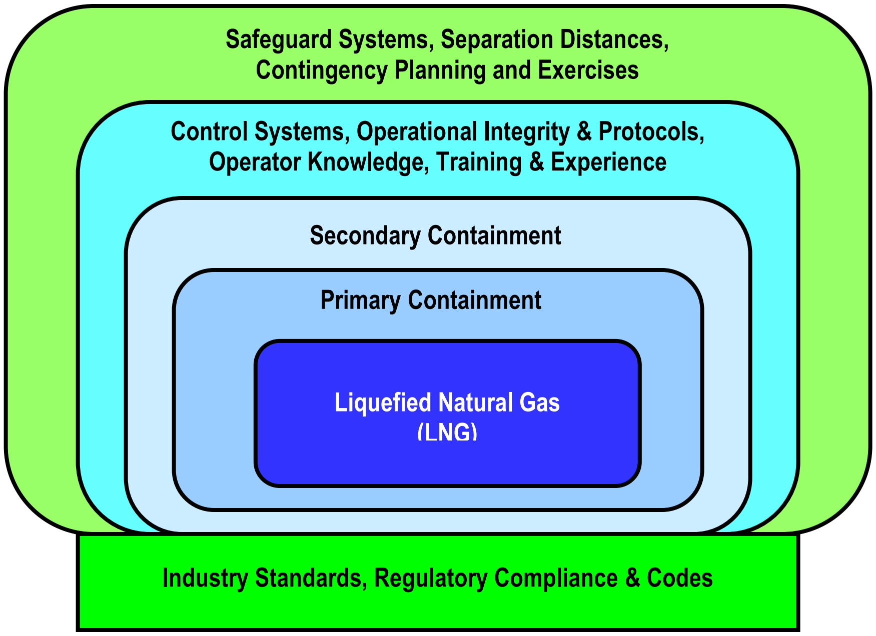
Multiple Safety Layers Manage LNG Risk



The GIIGNL Technical Study Group has developed this 7-paper series to provide public readers with factual information about the LNG industry's multiple layers of safety, as illustrated in the figure to the left.

The GIIGNL Information Papers include:

- No. 1 – Basic Properties of LNG
- No. 2 – The LNG Process Chain
- No. 3 – LNG Ships
- No. 4 – Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations
- No. 5 – Managing LNG Risks – Containment
- No. 6 – Managing LNG Risks – Industry Safeguard Systems
- No. 7 – Questions and Answers (Q&A's)

For more information about these and other topics, or to obtain copies of this report series contact:

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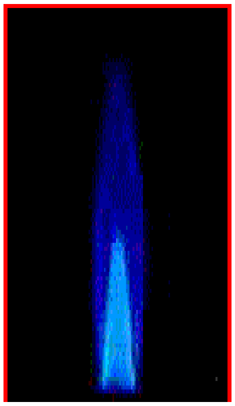

The LNG Process Chain

GIIGNL's Technical Study Group has overseen the development of this Information Series of 7 papers to provide factual information about Liquefied Natural Gas (LNG). In French, Spanish, Portuguese, or Italian speaking countries, the abbreviation GNL is used in place of LNG. This paper summarizes the components of the "LNG Process Chain" - the steps and industrial processes used in producing, storing, and delivering LNG to commercial and residential customers. LNG is used to transport natural gas economically from distant locations to consumers and to provide diversity and security for the gas supply. For more information, additional references and weblinks are provided at the end of this paper.

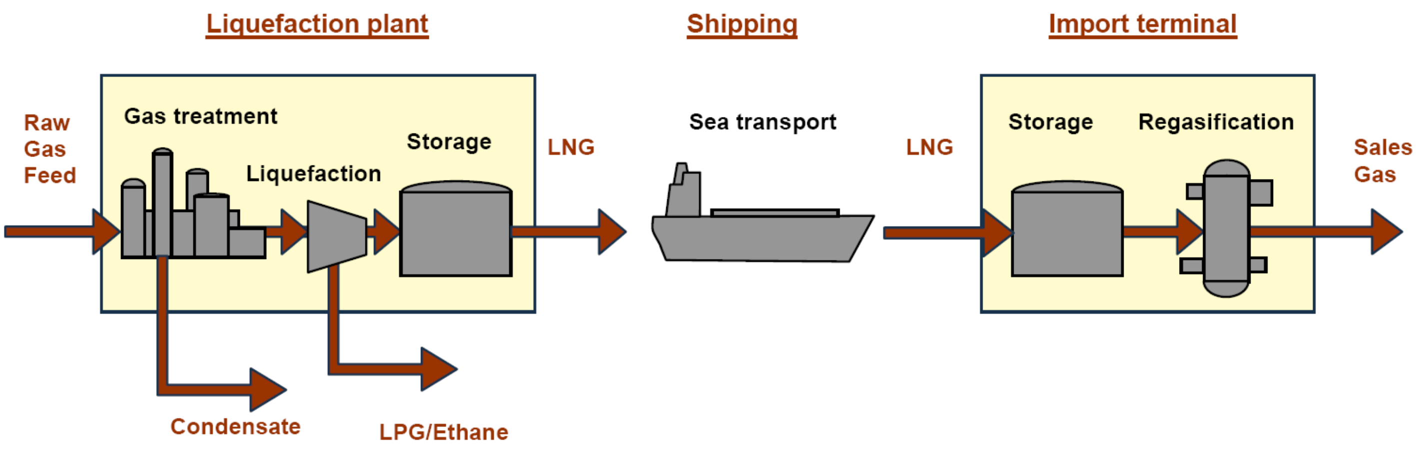

Figure 1. The LNG Process Chain - from Extraction, Processing and Transport, to Consumption (Source: BV 2009)

About LNG

Liquefied natural gas is natural gas, primarily composed of methane, which has been converted to liquid form for ease of storage and transport. LNG takes up about 1/600th the volume of natural gas. The conversion of natural gas to its liquefied form allows for the transport of greater quantities.

Liquefaction describes the process of cooling natural gas to -162°C (-259°F) until it forms as a liquid. LNG must be turned back into a gas for commercial use and this is done at regasification plants. This Information Paper describes the process used to produce and ultimately deliver LNG to consumers. This process is known as the LNG Process Chain.

The LNG Process Chain

Since 1964, LNG production, export, import and distribution has followed a process sequence similar to that illustrated in **Figure 1**.

A brief overview of the various steps along this chain is provided below.

Extraction

Extraction of the natural gas from the earth's surface is the first step along the process chain.

A majority of the world's LNG supply is exported from countries with large natural gas reserves (15 countries contain a total of 22 natural gas liquefaction plants at the beginning of 2008). These countries include Qatar, Algeria, Australia, Indonesia, Malaysia, Nigeria, Trinidad, Brunei, Norway, UAE, Egypt, and Russia with Yemen opening its first operational LNG plant during 2009. Other countries may produce natural gas for domestic use, like the US, but lack adequate supply to export on a large scale. In situations in which domestic gas supply is inadequate to meet intra-country demand, LNG is imported.

Once a potential natural gas field has been located by a team of exploration geologists and geophysicists, a team of specialists drills down to where the natural gas is thought to exist. After a well has been drilled and the presence of commercially-viable quantities of gas has been verified, the next step is to extract the natural gas (and/or oil) out of the ground and process it. At this point, the natural gas which is extracted from the ground is called "feed" gas. Before a commercial market for LNG existed, the gas associated with oil went unused and was wasted in a flare. Now it can be used as LNG.

It is important to emphasize that raw natural gas has to be purified before we can use it in our homes and factories. The natural gas we use as consumers is almost entirely methane, although natural gas is associated with a variety of other compounds and gases (e.g., ethane, propane, butane, pentanes, hydrogen sulphide [H_2S], carbon dioxide [CO_2], helium and nitrogen), as well as oil and water, which must be removed during production prior to liquefaction.

The Natural Gas Liquefaction Plant

Step two in the process chain is cleaning the natural gas at the liquefaction plant. A series of processing steps allows the separation and removal of the various extraneous compounds from the natural gas prior to liquefaction.

Production Purification

One of the primary purposes of the liquefaction plant is to provide consistent composition and combustion characteristics through the cooling and condensing of the natural gas so it may be loaded as LNG on tankers (ships or trucks) and delivered to the end user. The combustion characteristics and content consistency are critically important to obtain pipeline-quality gas. Pipeline-quality natural gas typically contains 85% to 99% methane. It also contains the heavier hydrocarbons and other substances which are not removed during the processing. **Figure 2** provides a summary of the stripping process that is used to remove many of the compounds present in the feed gas as it comes out of the ground, prior to beginning the liquefaction process.

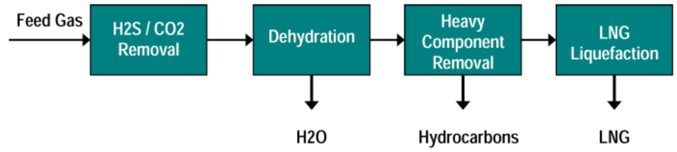

Figure 2. The production process flow for natural gas prior to liquefaction (Source: BV 2009)

More specifically, carbon dioxide and water are extracted upstream of liquefaction or they would cause damage to liquefaction facilities by freezing. Hydrocarbons heavier than methane are sometimes also separated and sold as raw materials to the petrochemical industry or used as fuel.

Liquefaction

Following the removal of most contaminants and heavy hydrocarbons from the feed gas, the natural gas advances within the facility to undergo the liquefaction process. The natural gas being converted to its liquefied form is almost entirely methane at this point. To obtain maximum volume reduction, the gas has to be liquefied through the application of refrigeration technology which makes it possible to cool the gas down to approximately -162 °C (-256°F) when it becomes a liquid.

At that point, LNG is a non-corrosive liquid that is clear and colourless like water, but weighs about half as much as the same volume of water. One volume of LNG equals approximately 600 volumes of natural gas at standard temperature (15.6ºC/60 ºF) and atmospheric pressure. Stated a different way, the liquid form occupies a volume 600 times smaller than the same amount of natural gas. It is this ratio of liquid to gas that makes LNG economically attractive for transport in bulk volumes by ship or truck.

LNG Transportation

Step three in the LNG process chain is transporting the liquefied natural gas to the consumer. Primary modes are by sea and truck and in a few locations by rail (Japan).

By Sea

When LNG is to be transported any great distance, it is most often transported by sea in specialized LNG Carriers. The first voyage of the MV Methane Pioneer in 1959 was from Lake Charles, Louisiana, to Canvey Island, United Kingdom. Commercial voyages began in 1964 on the MV Methane Progress and MV Princess from Algeria to Canvey Island. Safety systems on LNG carriers and the training of the crews that operate the vessels have evolved by a process of continuous improvement and are now robust. Over 45,000 voyages have been completed without an incident which resulted in a loss of cargo.

Today, LNG is transported on double-hulled ships specifically designed to contain the cargo at or near atmospheric pressure at a cryogenic temperature of approximately -162°C (-259°F) (**Figure 3**). LNG carriers are a blend of conventional ship design with specialized materials and advanced systems for handling cryogenic cargoes. The containment tanks have layers of insulation which isolate the LNG cargo from the hull by ensuring a minimum distance from the sides and bottom of the hull per the IGC (IMO International Gas Codes) and add layers of protection in the event of grounding or collision. LNG Ships are described in more detail in **Information Paper No. 3**.

Figure 3. Examples of LNG carrier types: top – membrane design; below – Moss sphere design. (Source: BV 2009)

Additionally, this insulation system limits the amount of LNG that boils off or evaporates during the voyages. On many LNG vessels, boil-off gas is used to supplement fuel during the voyage.

There are stringent international regulations regarding the construction and operation of LNG Carriers at sea and in port. The International Maritime Organisation (IMO) is the agency of the United Nations responsible for adopting and updating international treaties (called conventions) for shipping safety and security. IMO has adopted approximately 40 conventions and protocols, including the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO Gas Code) and the International Maritime Dangerous Goods Code.

Approximately 300 LNG ships are in service and the majority of them can each carry 120,000 to 175,000 m^3 (31 to 43 million gallons) of LNG. New vessel construction has increased the LNG carrier ship cargo capacity up to 267,000 m^3 (71 million gallons). The cost of LNG ships today is between $225-250 million for a 135,000 m^3 carrier up to approximately $300 million for the larger ships.

By Truck

In areas around the world where a liquefaction plant is in the vicinity of regasification facilities, the most cost-effective transportation mechanism for LNG is by tank truck. Using specialised, double-skinned tank trucks, liquefied natural gas can be transported to a regasification facility quickly and effectively. In many parts of the world, trucking has been used for the transportation of LNG since 1968. LNG trucking is now a mature industry, using tanker trucks of 6 to 20 tonnes which meet industry requirements. LNG is regularly transported by tank truck in several countries, including but not limited to the US, Japan, Korea, the UK, Norway, Germany, Belgium, Spain, Portugal, China, Brazil, Turkey and Australia.

LNG Receiving and Regasification Terminals

The fourth step in the LNG process chain involves the import terminals, which are marine or waterfront facilities. LNG carriers deliver the LNG to a marine terminal where the LNG is stored before undergoing regasification, which converts the LNG back into its gaseous form.

Currently about 63 LNG import terminals (regasification plants) operate worldwide. The largest importers of LNG recently are Japan, South Korea, Taiwan and India on the Asian continent, the US, Mexico, Brazil, Argentina, and Chile in the Americas, and a number of European countries such as Belgium, France, the UK, Portugal, Italy and Spain. China, Mexico, Argentina, Brazil and Chilie also now import LNG. An overview of importing countries throughout the world is reflected in **Figure 4**.

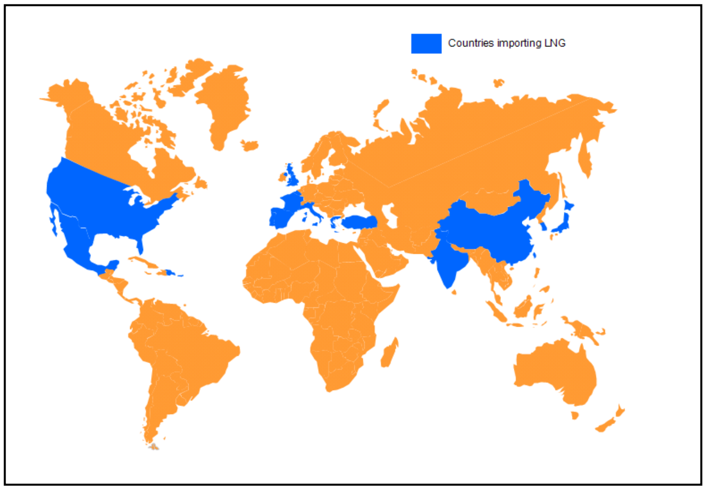

Figure 4. Countries with the greatest LNG imports world-wide (Source: BV 2008)

LNG can also be delivered to offshore terminals which are LNG ships constructed to function as Floating Storage and Regasification Units (FSRU), or, if no storage is needed, Floating Regasification Units (FRU). Floating facilities allow LNG terminals to be sited offshore. Regasification ships are operating in Argentina, Brazil, the UK and the US.

Another type of facility which may receive LNG by ship is known as a peak-shaving facility. These plants, which may be operated by utilities, store LNG in tanks until it is needed at times of peak demand. An LNG peak-shaving facility is normally connected to the gas-supply system and may consist of LNG liquefaction equipment to convert the natural gas into LNG, LNG storage tank(s), pumps, vaporisers and other equipment to turn the LNG back from a liquid to natural gas. In some cases peak-shaving facilities are filled using road tankers from an import terminal.

There are different designs of LNG import terminals but the overall process is often quite similar. A typical LNG import terminal process flow diagram is shown in **Figure 5**. The major equipment components of an LNG import and regasification terminal are:

- Unloading arms,
- Cryogenic pipelines,
- Storage tank(s),
- Low pressure pumps,
- Boil-Off Gas (BOG) compressors and re-condensers,
- High pressure (HP) pumps, and
- Vaporisers.

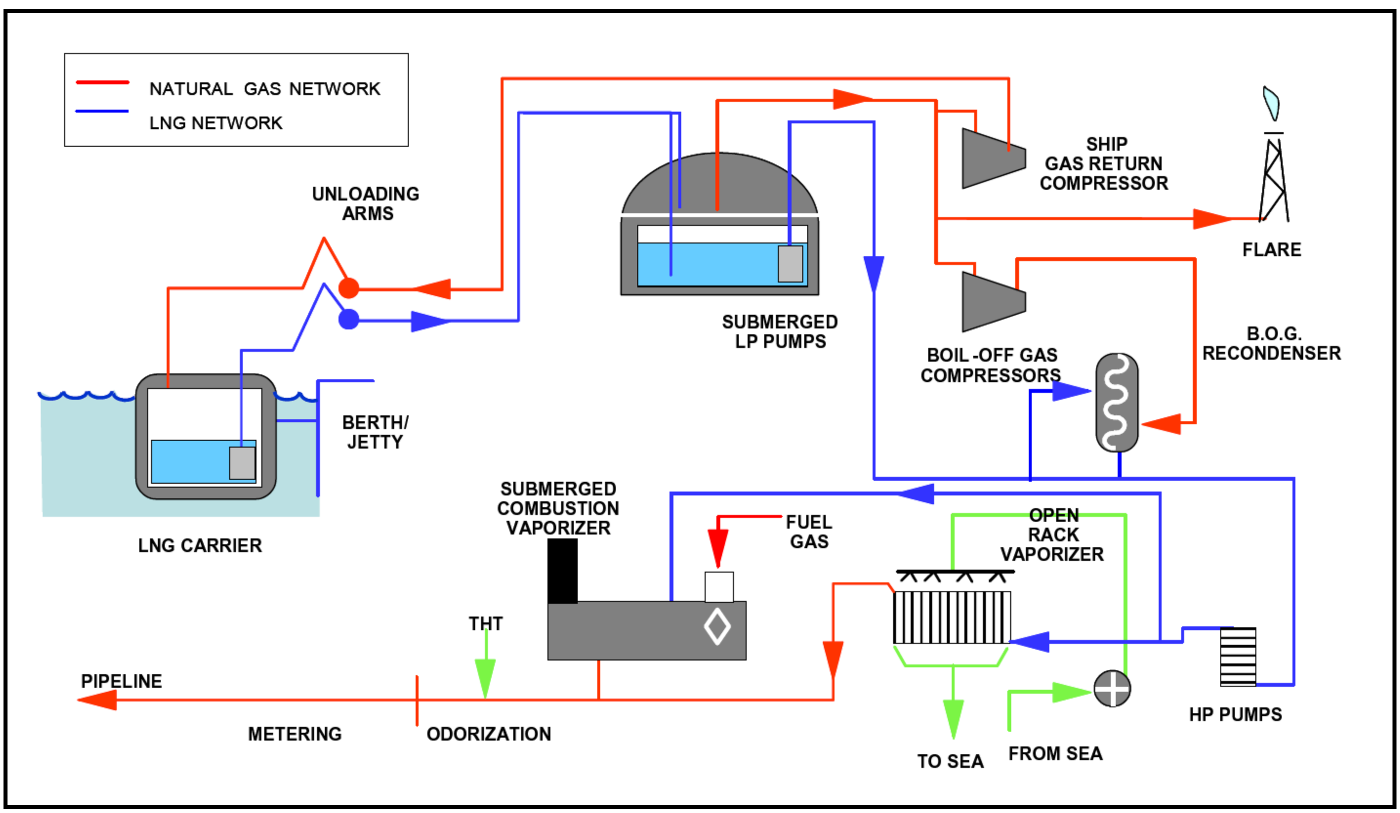

Figure 5. Example LNG import terminal process (Source: BV 2009)

Boil-off gas is the vapour produced above the surface of a boiling cargo due to evaporation, which is caused by heat ingress or a drop in pressure.

Since natural gas is odourless, odorisation of the re-gasified natural gas is required in many regions and countries before it is distributed to consumers. A typical odorant is THT (tetrahydrothiophene) or mercaptan.

Unloading

LNG unloading operations use articulated arms which are specifically designed to transfer cargo safely from the ship to the terminal. These articulated arms are called "hard-arms" and are the connection between the ship's manifold system (piping connection) and the terminal. A picture of hard-arms connecting the ship and terminal is shown in **Figure 6**.

Figure 6. Unloading arms at an import (receiving) terminal (Source: BV 2009)

Once the LNG carrier is moored, loading arms are gradually chilled to -162°C (-259°F) prior to the beginning of LNG unloading operations. The unloading arms are able to endure the expansion and contraction which results from changes in temperature.

A risk during unloading is the potential extension and rupture of unloading arms due to ship movements. Consequently, these arms are equipped with emergency disconnect systems. To protect both the ship's manifold connection and the terminal's hard arms, a Power Emergency Release Coupler (PERC) is fitted into most hard arm installations.

This system allows the rapid disconnection of the LNG carrier from the terminal while limiting the amount of LNG released. There are also position detectors to check that the ship is not moving too vigorously (in a manner likely to break the arms). These detectors can activate the emergency disconnection system. The PERC is comprised of two ball valves and an emergency release coupler. If the vessel moves outside of the normal operating range for the hard arms, an ESD (emergency shutdown device) will be activated automatically and cargo transfer will be stopped. Further movement of the vessel outside of the operating range will activate the emergency release system. The ball valves will close and the emergency release coupler will operate. One ball valve remains attached to the ship and the other stays attached to the hard arm. The PERC system may also be activated by an operator. This system is designed to trap the minimum amount between the valves which could be spilled upon release.

Storage

After unloading, LNG is transferred via cryogenic pipelines to insulated storage tanks specifically built to hold LNG.

There are three kinds of facilities where LNG can be stored: onshore import terminals, offshore import terminals and peak-shaving facilities.

LNG storage tanks are designed to withstand cryogenic temperatures, maintain the liquid at low temperature, and minimize the amount of evaporation. The small part of LNG which evaporates is called "boil-off gas". The temperature within the tank will remain constant if the pressure is kept constant by allowing the boil-off gas to escape from the tank. This gas is captured and: a) re-condensed to be sent to the vaporiser with LNG or compressed and sent to the pipeline; or b) re-injected into the LNG carrier to maintain positive pressure during the unloading of the ship; or c) only in abnormal or accidental situations, sent to the flare.

The storage facility is designed with a venting feature as an ultimate protection against risk of overpressure due to a "roll-over" condition in the LNG tank. LNG "rollover" refers to the rapid release of LNG vapours from a storage tank, resulting from stratification. The potential for rollover arises when two stratified layers of different densities (due to different LNG compositions) exist in a tank. To prevent rollover, special instruments called densitometers are used to monitor the development of the layers within the tank, thereby allowing the operator to mix the LNG within the tank or with that in other tanks to break up the stratification.

An import terminal usually has two or more LNG storage tanks. The types of tank types, described further in **Information Paper No. 5**, are:

- Single containment tanks,
- Double containment tanks,
- Full containment tanks,
- Membrane tanks, and
- In-ground tanks.

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Re-gasification

Next, the LNG stored in the tanks is sent to vaporisers which warm and regasify the LNG. As this occurs, LNG stored in the tanks is evaporating. Once the boil-off gas is also re-condensed, LNG is sent to vaporisers. This will avoid flaring or venting boil-off gas for most operating conditions.

The main types of vaporisers used in the LNG industry are Open Rack Vaporisers, Submerged Combustion Vaporisers, Intermediate Fluid Vaporisers and Ambient Air Vaporisers.

Open Rack Vaporisers (ORV)

Open Rack Vaporisers (**Figure 7**) derive the heat necessary to vaporise LNG from seawater. The water is first filtered to avoid the presence of small solid particles in the ORV. It then falls onto panels of tubes containing LNG and then gathers in a trough underneath before being discharged back into the sea. The LNG passing through the tubes is heated and vaporises.

The tubes are specifically designed to optimise heat exchange.

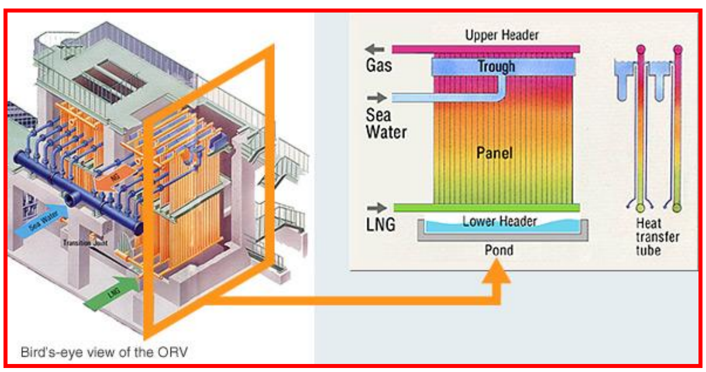

Figure 7. Open rack vaporiser (Source: Tokyo gas)

Submerged Combustion Vaporisers (SCV)

Submerged Combustion Vaporisers burn natural gas produced by the terminal and pass the hot gases into a water bath containing a tubular heat exchanger where LNG flows (**Figure 8**).

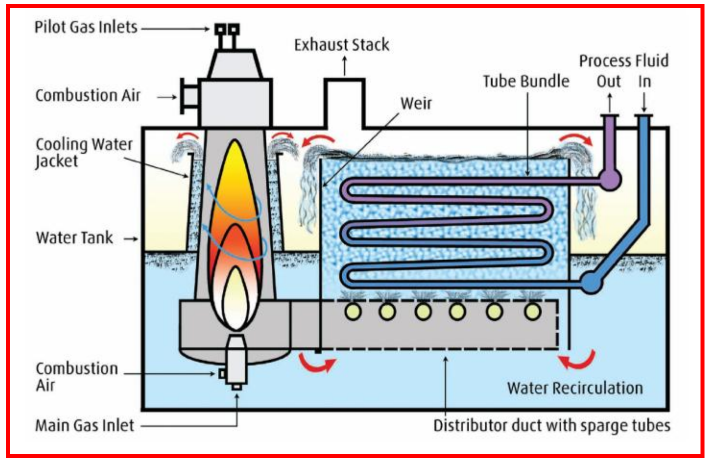

Figure 8. Submerged Combustion Vaporiser (Source: Selas Fluid Processing Corporation brochure)

The froth produced by the combustion gas increases the efficiency of heat transfer between the water and the LNG, and prevents ice from forming on the tube bundle. Submerged Combustion Vaporisers burn 1.2 to 1.5 % of the natural gas processed.

Intermediate Fluid Vaporiser (IFV)

An Intermediate Fluid Vaporiser relies upon two levels of thermal exchange: the first is between LNG and an intermediate fluid such as propane, and the second is between the intermediate fluid and a heat source which is usually seawater (**Figure 9**).

The surface area of the exchangers is designed to optimise the heat exchange. IFV's prevent freeze-up and reduce fouling risks. This particular operational benefit can justify the increased cost that arises from the use of an intermediate fluid.

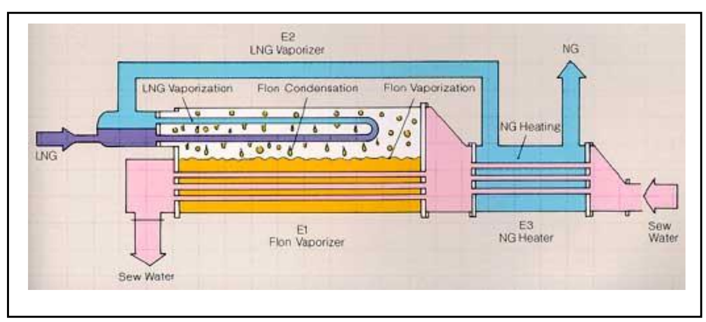

Figure 9. Intermediate Fluid Vaporiser (Source: Kogas)

Ambient Air Vaporisers (AAV)

This vaporiser uses the heat from the air. It is a proven technology and has generally been used for smaller installations such as LNG satellite terminals fed with LNG by road truck (**Figure 10**). The units may have natural convection of fan-assisted air flow. Some larger units have recently been installed at LNG import terminals where seawater systems are considered unsuitable.

Figure 10. Ambient Air Vaporiser (Source: BV 2009)

Odorisation, Send-out, and Delivery

Before natural gas is distributed to consumers, an unpleasant-smelling odour is added. Because natural gas is colourless and odourless, a leak is impossible to detect without appropriate instruments. To make the detection of a gas leak easier, whether it is in our kitchen or in a pipeline, an odorant is normally added to natural gas. The odorisation station can be in the LNG terminal itself before the send-out of natural gas, or just a few kilometers beyond the terminal. The point at which odorants are added depends on the country. Many terminals that export to a high pressure transmission line do not odorise.

Metering, the last step at the terminal, measures the quantity of gas which is being sent out. Natural gas is then delivered by pipeline directly to customers for industrial or residential use.

Key Points and Conclusions

In closing, the reader should remember the key points of this information paper:

1. The LNG Process Chain includes the Extraction, Processing, Liquefaction, Transport, Storage, Regasification and distribution to consumers of LNG.
2. Extraction of natural gas from commercially-viable, drilled wells produces "feed gas" which needs to be processed to commercial quality.
3. Processing of LNG includes cleaning it by separating and removing various extraneous compounds, including carbon dioxide and water.
4. Liquefaction of the natural gas, predominantly methane, is achieved by refrigeration down to approximately -162°C (-259°F).
5. Transport of LNG over long distances is by sea in specially-designed, double-hulled LNG ships, or over shorter distances by specialised, double-skinned tank trucks. Once LNG is regasified, natural gas is sent out to consumers through a pipeline distribution network.
6. LNG is delivered LNG to three kinds of facilities: onshore import terminals, offshore import terminals and peakshaving facilities. LNG is unloaded and transferred via cryogenic unloading arms and pipelines to specifically-designed, insulated storage tanks at these facilities.
7. LNG unloading operations in import terminals use articulated arms ("hard-arms") specifically-designed to safely transfer the LNG safely from the ship to the terminal.
8. Safety systems are designed into every single step of the "Chain". Examples include, during the Unloading Process, the Power Emergency Release Coupler (PERC), which safely disconnects the ship's manifold connection and the terminal's hard-arms in emergency situations, and Emergency ShutDown systems (ESD's), which immediately terminate the loading process with no leakage. These activate either automatically or manually.
9. Regasification of the LNG is accomplished by using one of a number of kinds of vaporisers.
10. Odors are added after regasification, then the natural gas is metered and sent out for delivery to the ultimate industrial or residential customers through a pipeline.

The excellent safety record for the LNG Process chain is a result of the LNG industry's stringent design practices and diligent operating standards, enhanced and supported by strong regulatory oversight. In that specific regard, a graphic illustration of these "Multiple Safety Layers" is reflected in the figure on the last page. Subsequent papers in this series will include a discussion of the many ways in which LNG safety is assured, through Multiple Safety Layers, all firmly based on a foundation of solid Industry Standards, Regulatory Compliance and Codes. These "safety layers" include several key components of the industry's Risk Management framework. Included among them are Primary and Secondary Containment, Control Systems which promote Operational Integrity; Protocols, Operator Knowledge and Experience (which are reinforced by comprehensive and ongoing training). A protective umbrella of Safeguard Systems, Separation Distances, and Contingency Planning further enhances safe management of LNG.

Next, in **Information Paper No. 3**, we will review the LNG Ships used to deliver LNG to import terminals.

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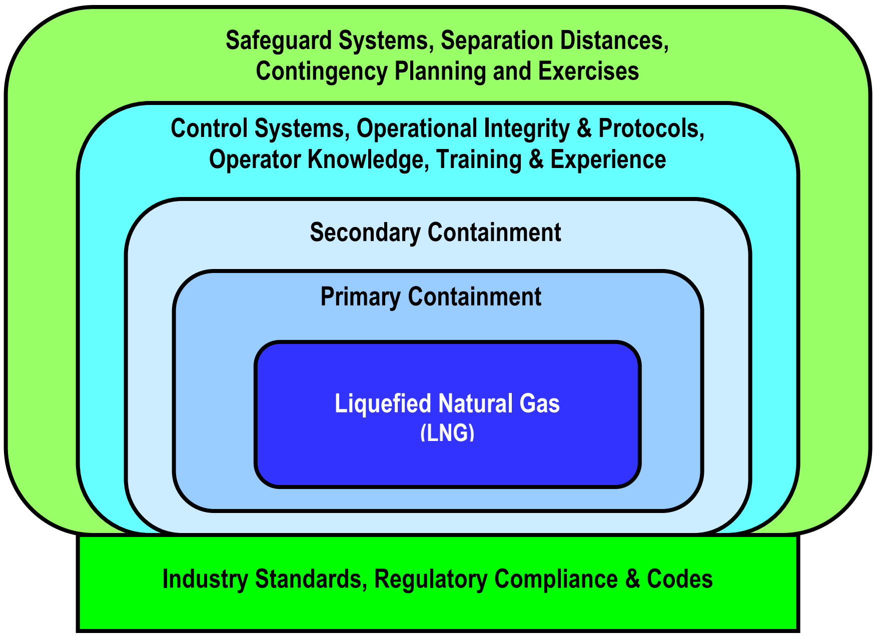
Multiple Safety Layers Manage LNG Risk



The GIIGNL Technical Study Group has developed this 7-paper series to provide public readers with factual information about the LNG industry's multiple layers of safety, as illustrated in the figure.

The GIIGNL Information Papers include:

- No. 1 – Basic Properties of LNG
- No. 2 – The LNG Process Chain
- No. 3 – LNG Ships
- No. 4 – Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations
- No. 5 – Managing LNG Risks – Containment
- No. 6 – Managing LNG Risks – Industry Safeguard Systems
- No. 7 – Questions and Answers (Q&A's)

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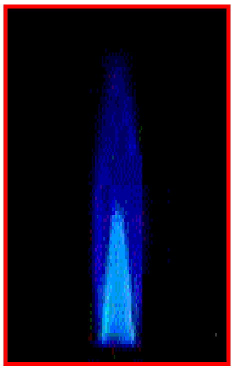
GROUPE INTERNATIONAL DES IMPORTATEURS DE GAZ NATUREL LIQUÉFIÉ

THE INTERNATIONAL GROUP OF LIQUEFIED NATURAL GAS IMPORTERS

LNG Information Paper No. 3



LNG Ships

G

GIIGNL's Technical Study Group has overseen the development of this Information Series of 7 papers to provide factual information about Liquefied Natural Gas (LNG). In French, Spanish, Portuguese, or Italian speaking countries, the abbreviation GNL is used in place of LNG. This paper explains how LNG is transported in large ships known as LNG carriers. This paper also summarizes the international security measures established by the International Maritime Organisation (IMO) to assure safe and secure transits around the world. For more information on these topics, additional references and weblinks are provided at the end of this paper.

Introduction

LNG ships, or carriers, provide the link in the LNG Chain (**Information Paper No. 2**) between where the natural gas is liquefied and where it can be regasified. LNG ships enable large amounts of clean natural gas energy to be transported to the consumer over large distances from the LNG Liquefaction Plant. The LNG is delivered to marine import terminals where the LNG is warmed and converted back into a gas, through a regasification process, before being delivered into the gas pipeline network. LNG can also be distributed to consumers in road tank trucks.

Over 1,500 liquefied gas ships operate around the world, most of which transport liquefied petroleum gas (LPG). There are approximately 320 LNG ships currently involved in worldwide trade. In comparison, there are approximately 12,000 oil tankers; of those approximately 800 are very large crude carriers (VLCC's).

Shipping Safety Record

The LNG shipping industry has an excellent safety record. Since the first cargoes of LNG were shipped on a regular commercial basis in 1964, over 56,000 shipments have been made without a single incident of LNG being lost through a breach or failure of the ship's tanks.

There have been three major grounding incidents, but none resulted in loss of cargo. The robust design of the ships and cargo tanks and the LNG industry's extraordinary attention to safety details have collectively served to prevent the release of cargo and to facilitate this noteworthy safety record.

About LNG Ships

A typical modern LNG ship is approximately 300 metres (m) (975 feet) long, 43m wide (140 feet) wide and has a draft of about 12 m (39 feet). LNG ships vary in cargo capacity, from 1,000 cubic metres to 267,000 cubic metres, but the majority of modern vessels are between 125,000 cubic metres and 175,000 cubic metres capacity. Smaller LNG ships (1,000 – 25,000 cubic metres capacity) also operate in some l areas, such as Norway and Japan. LNG carriers are capable of speeds of up to 21 knots (oil tankers operate at 15-20 knots) in open waters.

The majority of LNG ships sailing today have been designed to carry LNG either in spherical tanks (Moss sphere design) or in geometric membrane tanks (membrane design) (**Figure 1**; next page). The technology may also be utilised to function as floating storage and regasification units (FSRU) in offshore receiving terminals. Floating facilities allow LNG terminals to be sited offshore. LNG ships with on-board regasification facilities are operating in Argentina, Brazil, the UK and the US (**Figure 2**; next page).

Figure 1. Example LNG carrier types (top – Moss sphere design; below – membrane design) (Source: BV 2009)

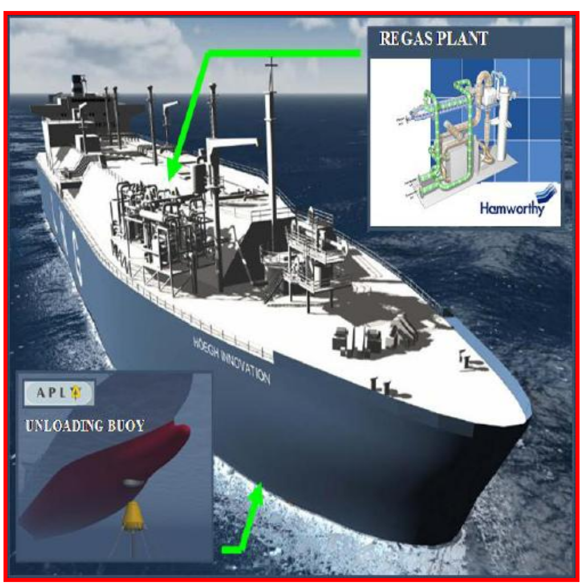


Figure 2. Shuttle and Regasification Vessel (SRV™) (Source: Höegh LNG)

LNG ships must comply with all relevant local and international regulatory requirements including those of the International Maritime Organisation (IMO), International Gas Carriers Code (IGC) and US Coast Guard (USCG).

All LNG ships have double hulls. The cargo is carried near atmospheric pressure in specially insulated tanks, referred to as the cargo containment system, inside the inner hull. International codes govern the design and construction of gas carriers. There are additional international requirements set out in the codes which vary with the type of cargo that the ship will carry. All commercial vessels have to be registered in a country – the "Flag State". Countries with more than one LNG ship in their registry include Algeria, Australia, The Bahamas, Bermuda, Brunei, France, Isle of Man, Italy, Japan, Korea, Liberia, Malaysia, Malta, the Marshall Islands, Norway, and United Kingdom. No inference can be drawn automatic-ally from a ship's flag of registry, the supplier of the cargo, or the nationality of the ship's crew to a particular characterisation of the importers.

All countries implement IMO Rules including the IGC, the International Safety Management (ISM) Code and the International Convention on Standards of Training, Certification and Watching (STCW) Convention. The government administration of the country of registry may impose additional requirements over and above the international codes.

A Classification Society is a non-governmental organisation which forms an integral part of the shipping industry, and is often referred to as "Class". It establishes and maintains standards for the construction and classification of ships and offshore structures, according to technical rules, confirms that designs and calculations meet these rules, and conducts surveys of ships and structures during the process of construction and commissioning. Classification societies periodically survey vessels in service to ensure that they continue to comply with the rules and required codes. Insurance underwriters require that the ships are "in class"; without insurance the ships cannot trade.

Marine quality assurance for LNG carriers (as well as other ships) is provided through the process of vetting, which assesses ship quality against a known standard to determine its acceptance for use. Ships are assessed in relation to such international conventions and industry recommendations as IGC, Safety of Life at Sea (SOLAS) and International Convention for the Prevention of Pollution from Ships (MARPOL). Guidance detailed in the International Safety Guide for Oil Tankers and Terminals (ISGOTT) is pertinent to all tanker types and the Society of International Gas Tankers Terminal Operators (SIGTTO) to gas carriers. The process of assessing the ship quality should include the assessment of operational standards of the vessel including crew competency and training, and the ship's physical condition. Information on ship quality is gathered from many sources, including vessel inspections on behalf of ship companies, owner assessments, terminal and operational feedback, market intelligence, casualty data, reputation and questionnaires. The "Port State Controls" established by the Memorandum of Paris (1981) are recorded in the "Equasis" database available for worldwide access. Such port state control databases and Class reports also provide information which assist in making the vetting decision. Generally, operators perform ship inspections according to the Oil Companies International Marine Forum (OCIMF) standards or to their own standards to assess the ship conditions. Reports on the ship's technical and survey status are available through the OCIMF Ship Inspection Report (SIRE) Programme, via the ship's classification society, and through the ship owner.

General Operational and Safety Facts

In addition to the aforementioned safeguards for the LNG ships, the entire LNG shipping process is replete with sophisticated operational and safety systems. Operationally, the ships use communications technology, global positioning and radar to continuously monitor the ship's course, speed and position (as well as that of nearby vessels). Additionally, comprehensive safety systems begin monitoring the precious (LNG) cargo at the very outset of the loading process, and –at that point – initiate the constant procedure of checking for leakage. Such checks start when the gas is loaded into the ship's pre-cooled cargo tanks as a refrigerated liquid at atmospheric pressure via a closed system from insulated storage tanks at the liquefaction plant. In a modern membrane LNG ship, the cargo containment system consists of a primary barrier, a layer of insulation, a secondary barrier, and a second layer of insulation as shown in **Figure 3**. Thus, if there should be any damage to the primary barrier, the secondary barrier will prevent leakage. The insulation spaces are filled with nitrogen and continuously monitored for any sign of leakage. The equipment used for tank detection is so sensitive that it can detect leakage through a hole the size of a pinhead. The LNG is kept fully refrigerated by allowing a small amount of cargo to evaporate during the voyage to the import terminal. This is referred to as boil-off gas (BOG); in addition to keeping the LNG cold, it provides a source of clean fuel for the ship's engines.

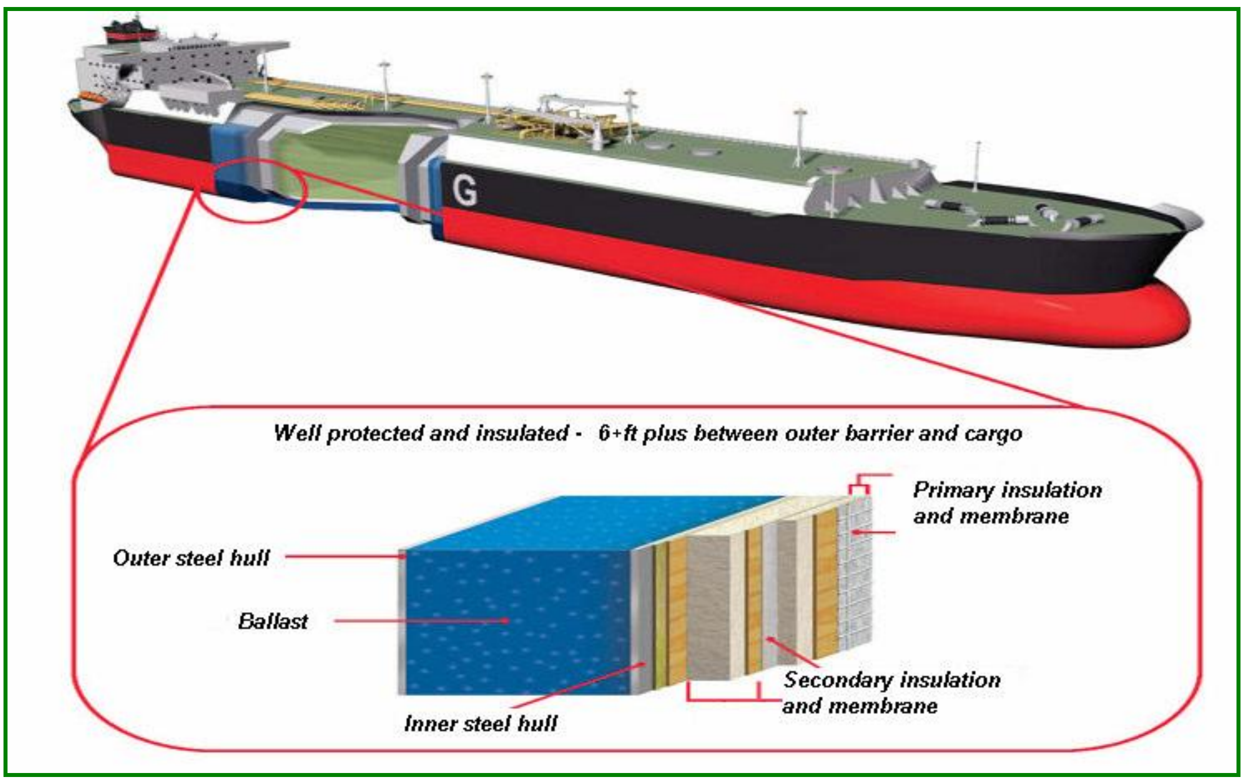


Figure 3. Example tanker safety construction requirements for LNG transport at sea (Source: BP Shipping)

Training

The LNG ship's officers and crew undergo extensive training to meet internationally recognised standards. The ships carry detailed contingency plans to cover the vast spectrum of potential incidents and conduct regular exercises to ensure that all crew members know how to respond effectively and efficiently during any emergency. All receive specific LNG training in cargo handling, fire-fighting and relevant safety systems, including drills encompassing various scenarios related to the cargo and the vessel itself.

When the LNG ship arrives at the import terminal, it is pumped from the ship into onshore storage tanks. Before this transfer takes place, a pre-discharging meeting is held on board during which a safety checklist is completed to comply with international guidance by organisations such as IMO, SIGTTO, and ISGOTT. Special cryogenic transfer arms are used to transfer the LNG from the ship to shore. When the loading and unloading operations are taking place, the ship and terminal are connected by means of a special Emergency Shut Down (ESD) system which enables cargo transfer to be shut down automatically and rapidly in case of any problems. Some modern LNG ships are fitted with a reliquifier to conserve boil-off gas.

From the onshore tanks, the LNG is pumped to the regasification plant, i.e., warmed and converted back into a gas, before entering into the pipeline distribution system.

Shipping Security

Shipping safety and security risks are managed through the use of strict operational procedures, putting a priority on safety, and on well-trained, well-managed crews. Safety and security assurance is a key part of company hiring, training and operations practices.

As a result of the acts of terrorism in the US on September 11, 2001, IMO agreed to new amendments to the 1974 SOLAS (International Convention for the Safety of Life At Sea) addressing port facility and ship security. In 2003, IMO adopted the International Ship and Port Facility Security (ISPS) Code. This code requires that vulnerability assessments be conducted for ships and ports and that security plans be developed. The purpose of the ISPS code is to prevent and suppress terrorism against ships; improve security aboard ships and ashore; and reduce risk to people (including passengers, crew, and port personnel on board ships and in port areas), and to vessels and cargoes. Cargo vessels 300 gross tons and larger, including all LNG vessels, as well as ports servicing those regulated vessels, must adhere to these IMO and SOLAS standards.

For ships, IMO requirements include:

- Ships must develop security plans and have a Ship Security Officer;
- Ships must be provided with a ship-security alert system. These alarms transmit ship-to-shore security alerts to a competent authority designated by the Administration, which may include the company, identifying the ship, its location and indicating that the security of the ship is under threat or has been compromised;
- Ships must have a comprehensive security plan for international port facilities, focusing on areas having direct contact with ships; and
- Ships also may have certain equipment onboard to help maintain or enhance the physical security of the ship.

For port facilities, IMO requirements include the following:

- Port facility security plan;
- Facility Security Officer; and
- Certain security equipment may be required to maintain or enhance the physical security of the facility.

For both ships and ports, security plans must address the following issues:

- Monitoring and controlling access;
- Monitoring the activities of people and cargo;
- Ensuring the efficacy of security communications procedures and systems, and their ready availability; and
- Completion of the Declaration of Security. A Declaration of Security (DOS) is a declaration which addresses the security requirements that could be shared between a port facility and a ship (or between ships) and stipulates the responsibility for security each shall take.

Security plans also address issues such as: port of origin, port of destination, control of ship movements, cooperation with shipping authorities and appropriate internal and external communications.

In addition to the security measures listed above, in the US the USCG requires additional security measures based on a location-specific risk assessment of LNG shipping including among other things:

- Inspection of security and carrier loading at the port of origin;

- On-board escort to destination terminal by USCG "sea marshals"; and
- Ninety-six hour advance notice of arrival (NOA) of an LNG carrier.

Shipping Safety Zones

In most ports, the LNG ships transit through port areas in a moving "safety zone" until they berth and then a fixed safety zone around them is established. This fixed zone exists while they discharge cargo, for about 24 hours, until they transit back out again. The safety zone is a way to keep other vessels away from the LNG carrier so as to prevent accidental collisions and intentional attacks. The concept of a safety zone is not unique to shipping. Similarly, the aviation industry applies safety zones to aircraft. The size of the safety zone for a specific port is determined by assessing the potential risks and hazards in that port and its approaches. A tug escort is used to manage the safety zone around a vessel. In operating the safety zone, the ports also have to manage and coordinate all their other shipping traffic. Specialised companies work with the host port authority and coast guard authorities to carry out a risk assessment, which determines the optimal configuration and management of safety zones.

Key Points and Conclusions

In closing, the reader should remember the key points of this information paper:

1. A typical modern LNG ship, or LNG carrier, is approximately 300 m long, 43 m wide and has a draft of 12 m. Cargo capacities range from 1,000 cubic metres up to 267,000 cubic metres. Sailing speeds approach 21 knots.
2. The main types of cargo containment on LNG ships are spherical (Moss sphere design) or geometric membrane (membrane design). Classification societies maintain standards for design and construction and conduct surveys while under construction and throughout a ship's service life. Insurance underwriters require that ships are "in class"; without insurance the ships cannot trade.
3. LNG ships must comply with all relevant local and international regulatory requirements, including but not limited to those of the IMO, IGC and the USCG.
4. Marine quality assurance for LNG carriers is provided through the process of vetting, which assesses ship quality against a known standard to determine its acceptance for use. Vetting is conducted by shipping companies using employees or independent contractors on their own ships as well as chartered ships.
5. Clearly, shipping safety and security for LNG ships is maintained at a very high level, especially considering the very low historical accident/incident rate of the industry. As recently reported by MSNBC, LNG tankers have sailed over 100 million miles without a shipboard death, major accident, or loss of cargo.

This excellent safety record is a result of the LNG industry's stringent design practices and diligent operating standards, enhanced and supported by strong regulatory oversight. In that specific regard, a graphic illustration of these "Multiple Safety Layers" is reflected in the figure on the last page. These "safety layers" include several key components of the industry's Risk Management framework. Included among them are Primary and Secondary Containment, Control Systems which promote Operational Integrity; Protocols, Operator Knowledge and Experience (which are reinforced by comprehensive and ongoing training). A protective umbrella of Safeguard Systems, Separation Distances, and Contingency Planning further enhances the safe management of LNG.

Next, in **Information Paper No. 4** we will review the codes, standards, regulatory compliance requirements and industry organisations which together comprise the foundation for safely managing LNG in import terminals and the interface with the LNG carriers.

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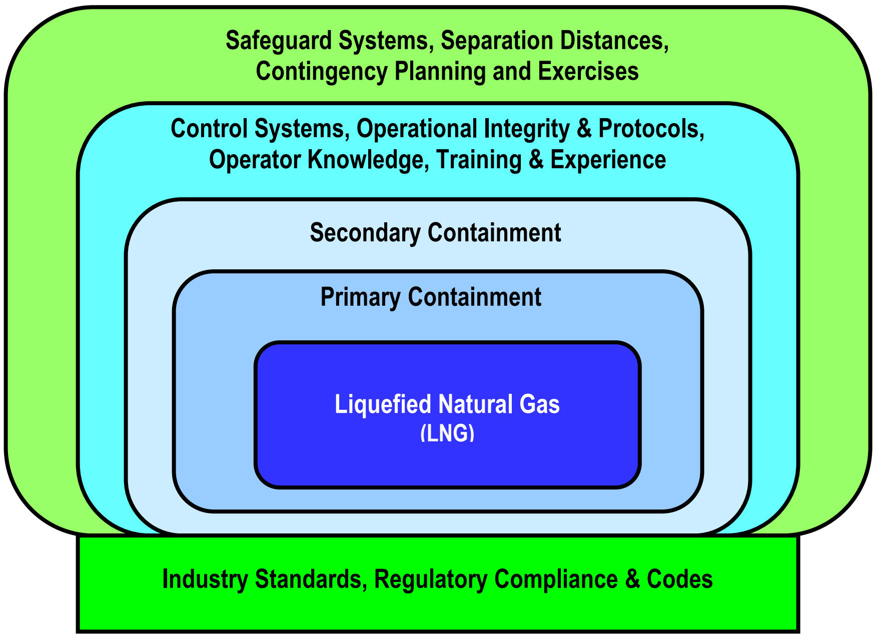
Multiple Safety Layers Manage LNG Risk



The GIIGNL Technical Study Group has developed this 7-paper series to provide public readers with factual information about the LNG industry's multiple layers of safety, as illustrated in the figure.

The GIIGNL Information Papers include:

- No. 1 – Basic Properties of LNG
- No. 2 – The LNG Process Chain
- No. 3 – LNG Ships
- No. 4 – Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations
- No. 5 – Managing LNG Risks – Containment
- No. 6 – Managing LNG Risks – Industry Safeguard Systems
- No. 7 – Questions and Answers (Q&A's)

For more information about these and other topics, or to obtain copies of this report series contact:

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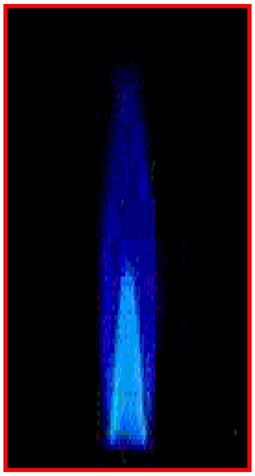
LNG Information Paper No. 4



Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations

GIIGNL's Technical Study Group has overseen the development of this Information Series of 7 papers to provide factual information about Liquefied Natural Gas (LNG). In French, Spanish, Portuguese, or Italian speaking countries, the abbreviation GNL is used in place of LNG. This paper describes the safety requirements for Liquefied Natural Gas (LNG) projects, which are established by regulations, classification societies, codes, standards, and industry associations. Cumulatively, they help assure the operational integrity of LNG facilities and ships and form one of the layers of protection to manage safety risks to facility workers and the public. For more information on these topics, additional references and weblinks are provided at the end of this paper.

Introduction

The most important safety requirement for the industry is to safely process, store, and transport LNG. There are a number of guidance documents and requirements which are intended to assure the safe operation of onshore and offshore LNG facilities, personnel and ships. Strict adherence to government regulations, codes, and standards has led to the LNG industry's exemplary safety record. Sharing best practices through non-profit trade organisations has also served to strengthen the safety culture of the entire industry.

LNG ships must comply with all relevant local and international regulatory requirements including those of the International Maritime Organisation (IMO), International Gas Carriers Code (IGC) and the US Coast Guard (USCG). For additional information on the regulations, codes and standards which apply to LNG ships, please refer to **Information Paper No. 3**. This Information Paper focuses primarily on the import terminal.

There are 63 LNG onshore import terminals (regasification plants) located worldwide in 2009. In 2007, the largest importers of LNG were India, Japan, South Korea and Taiwan on the Asian continent, the United States in theAmericas and a number of European countries such as Belgium, France, Italy, Portugal, Spain and the UK. Argentina, Brazil, Chile, China and Mexico also now import LNG. Offshore (floating) import terminals, also described in **Information Paper No. 3**, are an alternative to onshore facilities. Offshore regasification facilities are currently operational in Argentina, Brazil, the UK, and the US.

Government Regulations

The intent of regulatory authorities is to reduce the risk of adverse environmental consequences, damage to the equipment, facilities or ships and – most importantly – human casualties. This is achieved by various means in different parts of the world. In Europe, project applicants are required to conduct a safety risk assessment according to accepted methodologies and submit the results of these studies to the permitting agencies for review. European regulations usually focus on the outcomes, rather than the specific ways to achieve the desired level of safety.

European Council Directive 96/82/EC (SEVESO II) is aimed at the prevention of major accidents involving dangerous substances, including LNG, and the limitation of their consequences. The provisions contained within the Directive were developed following a fundamental review of the implementation of Council Directive 82/501/EEC (SEVESO I). In particular, certain areas were identified in which new provisions seemed necessary on the basis of an analysis of major accidents which had been reported to the Commission since the implementation of SEVESO I. One such area is management policies and systems. Failures of the relevant management system were shown to have contributed to the cause of over 85% of the accidents reported. The Directive sets out basic principles and requirements for policies and management systems which are suitable for the prevention, control and mitigation of major accident hazards.

The US regulations do not prescribe formal methodologies for risk assessments. Rather, risk is evaluated by both the project applicant and regulatory authorities, using government guidance to target the specific issues which risk assessments should address. The US government's oversight of LNG facilities is provided by three federal agencies, which are under an Interagency Agreement:

Federal Energy Regulatory Commission (FERC). FERC grants federal approval for the siting and the construction of new onshore facilities and implements its authority over onshore terminals through the agency's regulations. FERC has the responsibility to issue a certificate to the facility and is the lead federal agency for review of environmental and safety concerns, including public comment meetings and review procedures

- U.S. Department of Homeland Security (DHS). USCG within DHS exercises regulatory authority over LNG facilities which affect the safety of port areas and navigable waterways. The USCG also establishes review criteria for evaluating a proposed deepwater port. A prime regulation governing the marine portion of an LNG terminal is 33 CFR Part 127, *Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas*. Individual terminals operate under site-specific USCG Operating Plans (OPLANS). The OPLANS require pre-arrival boarding and inspection including ship certificates, crew licenses, safety equipment, ship condition, ship's log and procedures. The USCG can deny entry to any US port or terminal at their discretion.
- U.S. Department of Transportation (DOT). The Pipeline and Hazardous Materials Safety Administration (PHMSA) within DOT has the authority to promulgate and enforce safety regulations and standards both for the transportation and storage of LNG and for interstate or foreign commerce under the pipeline safety laws. The Maritime Administration (MARAD), also within DOT, has licensing authority for the construction and operation of deepwater ports, including offshore (floating) import terminals. PHMSA regulations, contained in 49 CFR Part 193, *Liquefied Natural Gas Facilities: Federal Safety Standards*, are applicable to LNG import terminals and storage facilities.

Most states in the US also have regulations and permit requirements which are similar to the federal regulations. Some states have LNG-specific regulations. The state permitting and review activities are undertaken independently and tend to address local concerns. County and municipal governments also have jurisdiction in these matters, with broad discretion vested in the county fire marshal, city fire chief and town council. For marine operations, port authorities also have jurisdiction. In most cases, the various regulatory agencies and bodies issue pronouncements and regulations which are consistent and correlative, often reflected by cross-referencing between documents and/or incorporation of "pronouncement a" by reference in "pronouncement b".

In Japan, the regulatory agency involved in LNG terminal siting and operation is the Ministry of Economy, Trade and Industry (METI) which enforces the Gas Utility Industry Law, the Electricity Utility Industry Law and the High Pressure Gas Regulation Law. LNG terminal siting and operation must comply with one of these laws. For example, under the Gas Utility Industry Law, gas utility companies:

- Maintain a gas facility in accordance with an adopted technical standard,
- Define, submit and observe their companies' own security regulations, in order to ensure the safety of construction, maintenance, and operation of gas facilities,
- Assign a gas-licensed engineer to ensure the safety of construction, maintenance and operation of a gas facility.

Codes and Standards

The LNG industry adheres to an international network of codes and standards which specify safe technologies, materials and designs for the construction of an import terminal. Codes and standards enable the industry to implement generally-approved technologies and ensure a high level of safety. The development and implementation of these codes and standards promotes sharing state-of-the-art technologies and research. Some of them, mainly European and American standards, are widely used throughout the world. The primary codes and standards are described in this paper. Compliance with additional codes and standards may be required in specific countries.

It is important to note that an international work group called **TC67 Work Group 10:** "Standardisation for Installations and Equipment for Liquefied Natural Gas, Excluding Product or Testing" was formed in 2006 under the ISO organisation (International Organisation for Standardisation). This group's objective is compatibility and harmonisation of LNG codes in order to raise the existing codes and standards among countries to an international level.

Some codes address specific safety risks to LNG import terminals from earthquakes in certain parts of the world. The main codes, NFPA 59A or EN1473, provide robust construction requirements to assure another rigorous level of protection against earthquake forces. Under these codes, for example, all companies must perform a site-specific investigation to determine ground motion risks and define seismic characteristics. This site-specific investigation will identify the probabilistic "maximum considered earthquake" (MCE). The LNG tanks and impounding system are then designed for two levels of seismic motion: (1) the "safe shutdown earthquake"; and (2) the "operating basis earthquake", both of which are defined in the main codes.

Europe

European Committee for Standardisation (CEN)

CEN is a private non-profit organisation whose mission is to "contribute to the objectives of the European Union and European Economic Area with voluntary technical standards which promote free trade, the safety of workers and consumers, interoperability of networks, environmental protection, exploitation of research and development programmes and public procurement."

In Europe, the codes and regulations specific to LNG import facilities include:

- **European Union Seveso II Council Directive** 96/82/EC of 9 December 1996 - *Control of Major-Accident Hazards involving Dangerous Substances*. For the European Union all operation and maintenance activities are under the control of a Safety Management System required by Directive Seveso II 96/82/EC. This pronouncement includes a revision and extension of the scope of Seveso I, the introduction of new requirements relating to safety management systems, emergency planning and land-use planning and a reinforcement of the provisions on inspections to be carried out by Member States.
- **EN 1473**: "Installation and equipment for LNG – Design of onshore installations" for storage capacities over 200 tonnes. The European code **EN 1473** is based on a risk assessment approach with fewer explicit prescriptive standards, compared to US regulations or US standards.
- **EN 1160**: "Installation and equipment for Liquefied Natural Gas – General characteristics of liquefied natural gas" This standard contains guidance on properties of materials that may come in contact with LNG in the facility.
- Additional codes include: **EN 14620**[1] **(**"Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and -165°C"), **EN 1474** ("Installation and equipment for LNG – Design and testing of LNG loading/unloading arms"); **EN 1532** ("Installation and equipment for LNG – Ship to shore interface"); and **EN 13645** ("Design of onshore installations with a storage capacity between 5 tonnes and 200 tonnes").

Applying their own regulations derived from the Seveso II Directive, national authorities of each European country have the responsibility to issue a certificate to the facility and are the lead agency for review of environmental and safety concerns, including public comment meetings and review procedures.

The following US standards may also be applied in Europe:

- NFPA 59A - Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG); and
- 33 CFR Part 127 - Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas.

US

American Petroleum Institute (API)

API maintains some 500 standards covering all segments of the Oil and Gas industry. One API standard that the LNG industry frequently uses is: API 620.

This standard is not applicable to all tank types because it contains rules for the design and construction details for

[1] **EN 14620** This standard originates from **BS7777** (British Standard: "Flat-bottomed, vertical, cylindrical storage tanks for low temperature service". Specification for the design and construction of single, double and full containment metal tanks for the storage of liquefied gas at temperatures down to -165°C").

double-walled, metal tanks. **Information Paper No. 5** describes types of LNG tanks in use today.

National Fire and Protection Association (NFPA)

NFPA is an international non-profit organisation which specialises in fire prevention and serves as an authority on public safety practices.

One NFPA standard that is frequently used in the LNG industry is:

- **NFPA 59A**: "Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)".

The **NFPA 59A** requirements are, for the most part, prescriptive as to the siting and design of an LNG facility. For example, this standard requires any LNG container to have an impoundment able to contain the volume which meets one of the following criteria:

- For an impoundment serving a single tank, the volume equals 110 percent of the LNG tank's maximum liquid capacity, or
- For an impoundment serving more than one tank, the volume equals 100 percent of all tanks or 110 percent of the largest tank's maximum liquid capacity, whichever is greater, or
- If the dike is designed to account for a surge in the event of catastrophic failure, the volume equals 100 percent.

NFPA 59A and **API 620** are widely used in the LNG industry.

Asia

- In Asia, specific standards have been developed for each area. The codes and regulations specific to LNG import facilities include:
- Gas Industry law, and
- Electricity Power Industry law.

Japan

The Japan Gas Association (JGA) is an organisation consisting of city gas utilities. One of the missions of JGA is to research the development of technical standards. JGA provides several recommended practices also used in other Asian countries:

- Recommended Practice for LNG In-ground Storage (JGA-107-RPIS)
- Recommended Practice for LNG Aboveground Storage (JGA-108-RPAS)
- Recommended Practice for LNG Facilities (JGA-102)
- Recommended Practice for Safety and Security in Gas Production Facilities (JGA-103).

These recommended practices have been developed using references from JIS (Japanese Industrial Standards) and API codes, among others. JGA-107-RPIS was developed by and is unique to Japan.

China

The Chinese LNG industry is currently using the international codes **NFPA 59A**, **EN 1473** and **NFPA 30**. Terminals incorporate some additional Chinese codes and standards, but these are largely limited to equipment and building specifications.

India

India has its own high-level code: "**OISD**[2] **STANDARD 194** – Storage & Handling of LNG", which is primarily based on the US standard **NFPA 59A**, with references to other OISD Standards. Elements are also taken from European LNG standards such as **EN1473**, as well as some British standards, and **API 620 Appendix Q**.

Taiwan

NFPA and API standards are used for the design of LNG terminals, along with British standards, **EN 1473,** and the JGA Recommended Practices for Liquefied Natural Gas.

Korea

Korean Gas (KOGAS) mainly uses international standards, as well as some Korean Industrial Standards.

These organisations provide and share overviews of the state-of-the-art technologies, best practices and high standards to support the development of the LNG industry. Indeed, if one company suffers from a poor public image because of an LNG incident, the entire industry's reputation will be impacted. It is therefore in the general interest of all companies within the industry to promote and achieve a high level of safety.

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[2] Oil Industry Safety Directorate

In addition to the codes and standards, the regulations of onshore plants, and the classification of LNG carriers, a number of international organisations exist to ensure a high level of safety.

Industry Associations

GIIGNL – International Group of Liquefied Natural Gas Importers

GIIGNL is a non-profit organisation, founded in 1971. GIIGNL's operational focus is the import terminal – those marine facilities which receive LNG by LNG ships. It is composed of 56 member companies involved in the importation of Liquefied Natural Gas, from over 18 different countries (in Asia, Europe and North America). GIIGNL provides its members with overviews of the general economic condition of the LNG industry and the most current state-of-the art LNG technology. This information enhances facility operations, strengthens the breadth and depth of contractual techniques, and supports industry positions with international agencies. GIIGNL members share information about commercial and technical developments in LNG, including safety incidents at member facilities. Activities of shared interest to GIIGNL members include the handling, importing, processing, purchasing, regasification, transportation and uses of LNG around the world.

One important example of proprietary information, shared only among industry members, is GIIGNL's LNG Incident Identification Study. This study began in 1992 and has been updated twice. To promote information-sharing among the industry, data is analysed without company names. The main aims of the study are to:

- Identify actual incidents of LNG or vapour release for possible inclusion in the hazard analysis of new, modified or existing facilities.
- Advise on the severity of the identified LNG incidents to assist in evaluation of their importance and potential consequences.
- Provide information on the circumstances under which the identified LNG incidents have occurred (and their frequency where possible) to assist in the evaluation of their relevance to the particular LNG facility under review.

In order to be as comprehensive as possible, the incident study aims to include all incidents known in the LNG Industry with the *potential* to cause damage to equipment or injury to personnel. GIIGNL members share this information to improve operational safety within the industry.

GIIGNL also coordinates and exchanges information on relevant studies with other organisations in the LNG industry, such as the International Gas Union (IGU), the Society of Gas Tanker and Terminal Operators (SIGTTO), Gas LNG Europe (GLngE), Center for LNG (CLNG) and Eurogas. The GIIGNL website is www.giignl.org.

SIGTTO – Society of International Gas Tanker and Terminal Operators

Founded in 1978, SIGTTO is a non-profit international society composed of more than one hundred members representing liquefied gas (LPG, LNG and others) tankers or liquefied gas marine loading or receiving terminals, or the operators of such tankers or terminals. While GIIGNL is concerned with import terminals, SIGTTO's focus is on shipping and its interface with marine terminal operations. The purpose of the organisation is to specify and promote high standards and best practices, and in so doing to maintain confidence in the level of safety achieved by the LNG industry.

This Society is an international body established for the exchange of technical information and experience, between members of the industry, to enhance the safety and operational reliability of gas tankers and terminals. To that end, the Society publishes studies and produces information papers and works of reference for the guidance of industry members.

SIGTTO maintains working relationships with other industry bodies, governmental and intergovernmental agencies, including the IMO, to better promote the safety and integrity of gas transportation and storage schemes. For twenty-five years, the Society has produced a steady flow of information, including recommendations and guidelines for industry members. These documents and reports represent SIGTTO's accumulated intellectual property, much of which has been adopted by regulatory authorities for the governance of gas shipping and terminal activities. It represents a compendium of reference work universally acknowledged as embodying *de facto* standards virtually throughout every niche within the liquefied gas transportation industry. SIGTTO's publications are listed on their website, www.sigtto.org. Some are downloadable but the majority are printed volumes available for purchase.

IGU – International Gas Union

The International Gas Union, founded in 1931, is a worldwide non-profit organisation. IGU has a very broad scope across the whole gas industry, including LNG export and import. The members of IGU are various associations and entities of the gas industries in 67 countries. IGU cooperates with many global energy organisations, and covers all the domains of the industry from exploration and production of natural gas on- or offshore, pipeline and piped distribution systems to customers' premises, and combustion of the gas at the point of use. The objective of IGU is to promote the technical and economic progress of the gas industry. The IGU website is www.igu.org.

CLNG – Center for Liquefied Natural Gas

The Center for Liquefied Natural Gas is another association of LNG producers, shippers, terminal operators and developers, energy trade associations and natural gas consumers. Based in the US, CLNG's purpose is to enhance the exchange of educational and technical information, and to facilitate the discussion of issues and the development of public policies which support the growth and operation of the LNG industry. CLNG also promotes public education and understanding about LNG by serving as a clearinghouse for related information. A number of recent LNG research reports can be downloaded from the site, www.lngfacts.org.

Ship Classification Societies

Classification societies are independent technical organisations. Their classification of ships assures all interested parties that each vessel is structurally and mechanically fit to carry crew and cargo. Another level of approval is certification by the societies, which provides assurance that at the time of certification the ship is fit for service.

Ship classification has long influenced the design, construction and maintenance of ship structures and engineering systems. The main classification societies for the LNG carriers are the American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV), Lloyd's Register (LR), and Nippon Kaiji Kentai Kyokai (NKKK). More discussion of ship classification can be found in **Information Paper No. 3**.

Key Points and Conclusions

In closing, the reader should remember the key points of this information paper:

1. The safe processing, storage and transportation of LNG is an essential condition for the continued existence, growth and sustenance of the entire industry.
2. Companies within the industry, governmental bodies and professional trade associations are all committed to the continued issuance of codes, guidance, regulations and standards intended to assure the safe operation of onshore and offshore LNG facilities, personnel and ships.
3. There are a number of international authorities which are instrumental to the creation, maintenance and dissemination of the diverse database, broadly defined, of LNG knowledge. Included most prominently among them are the International Maritime Organisation (IMO), International Gas Carriers Code (IGC) and the US Coast Guard (USCG). Each country with an LNG presence tends to have one or more governmental agencies monitoring, in varying fashion, their own LNG industry. By way of example for the US, such agencies include the Federal Energy Regulatory Commission (FERC), the Department of Homeland Security (DHS) and the Department of Transportation (DOT).
4. An extensive network of international work groups and associations includes, among other entities, **TC67 Work Group 10** (which addresses LNG equipment and installation standards); the European Committee for Standardisation (CEN), which has addressed or is addressing, among other things, the control of major accident hazards, equipment/installation design for onshore installations, and tank design and manufacture; and the American Petroleum Institute (API), which maintains some 500 standards covering all segments of the Oil and Gas Industry.
5. International gas industry associations serve, in various ways, to codify and disseminate LNG information and safeguards, including best practices. **GIIGNL** (the International Group of Liquefied Natural Gas Importers, founded in 1971), which is composed of 56 member companies in over 18 different countries, and focuses on the import terminal operations. **SIGTTO** (Society of International Gas Tanker and Terminal Operators, founded in 1978), which comprises more than 100 members, represents the operators of (LNG and LPG) tankers and liquefied gas marine loading or receiving terminals. **SIGTTO**'s focus is on shipping and its interface with marine terminal operations. The **IGU** (the International Gas Union, founded in 1931), spans the entire spectrum of the gas industry in 67 countries around the world. The **CLNG** (Center for Liquefied Natural Gas) is a broad association of LNG producers, shippers, terminal operators and developers in the US, as well as energy trade associations and natural gas consumers. Its purpose is to advance the exchange of educational and technical LNG information.
6. Ship Classification Societies review various aspects of ship quality, including mechanical fitness, security and safety of cargo capacity and structural integrity, as well as the professional competence and training of the crew. The Ship Classification process has long influenced the design, construction and maintenance of ship structures and related engineering systems.

Next, in **Information Paper No. 5**, we will discuss how LNG is contained in import terminals, which is essential to assuring LNG safety. As reflected in the illustration on the last page, the Multiple Safety Layers for LNG are all firmly based on a foundation of solid Industry Standards, Regulatory Compliance and Codes, many of which are developed by the foregoing associations and regulatory bodies. These "safety layers" include several key components of the industry's Risk Management framework. Included among them are Primary and Secondary Containment, Control Systems which promote Operational Integrity; Protocols, Operator Knowledge and Experience (which are reinforced by comprehensive and ongoing training). A protective umbrella of Safeguard

Systems, Separation Distances, and Contingency Planning further enhances the safe management of LNG.

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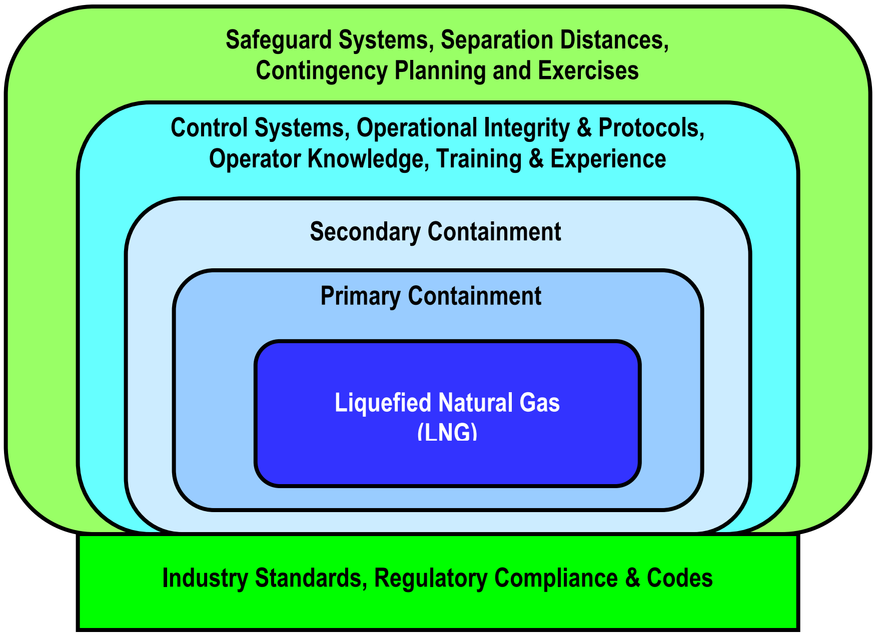
Multiple Safety Layers Manage LNG Risk



The GIIGNL Technical Study Group has developed this 7-paper series to provide public readers with factual information about the LNG industry's multiple layers of safety, as illustrated in the figure to the left.

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- No. 5 – Managing LNG Risks – Containment
- No. 6 – Managing LNG Risks – Industry Safeguard Systems
- No. 7 – Questions and Answers (Q&A's)

For more information about these and other topics, or to obtain copies of this report series contact:

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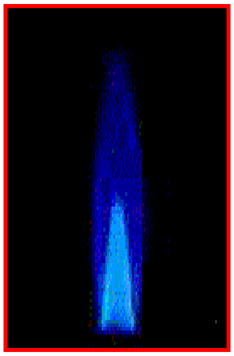
GROUPE INTERNATIONAL DES IMPORTATEURS DE GAZ NATUREL LIQUÉFIÉ
THE INTERNATIONAL GROUP OF LIQUEFIED NATURAL GAS IMPORTERS

LNG Information Paper No. 5



Managing LNG Risks – Containment

GIIGNL's Technical Study Group has overseen the development of this Information Series of 7 papers to provide factual information about Liquefied Natural Gas (LNG), or GNL in French, Spanish, Portuguese, or Italian speaking countries. This paper describes the tanks used to store LNG, which should be viewed as the primary means for safely containing LNG and preventing the exposure of LNG's extremely cold temperatures and flammable vapours to facility workers or the public. Secondary containment, i.e., ways in which the tank contents will be captured on site in the unlikely event of a leak or spill, is also discussed. For more information on these topics, additional references and weblinks are provided at the end of this paper.

Introduction

A primary safety requirement for the industry is to contain LNG. LNG is stored in large tanks at liquefaction facilities and import terminals. At an import terminal, LNG is stored until it is turned back into natural gas through regasification and then sent out to consumers in pipelines. A typical LNG import terminal has 2 to 4 LNG storage tanks (although a small number have over 10 tanks). LNG can also be imported and stored at an offshore receiving terminal.

LNG tanks have more than one means of containment. The first layer of containment is provided by the tank which holds the LNG. All LNG storage tanks are constructed with thermal insulation to prevent heat transfer, reduce evaporation, and protect the structure from cryogenic temperatures which could damage the structural integrity of the tank. Secondary containment is provided either by the use of dikes, berms and impoundment dams around storage tanks, or by building a second tank around the primary storage tank to contain the LNG in the unlikely event of a failure in the primary tank.

The decision to use a particular design is influenced by available space and local requirements. The vast majority of LNG storage tanks are above-ground. Japan has constructed some tanks below ground to save expensive land, and there are some floating storage tanks at offshore receiving terminals. This paper focuses on onshore storage tanks.

Storage Tanks

The tanks in which LNG is stored are the means for primary containment. Safe and secure containment is in part a function of the codes and standards which contribute to the operational integrity layer of protection (described in **Information Paper No. 4)**; these codes and standards define suitable engineering designs and specify appropriate materials for constructing storage tanks and other equipment at LNG facilities. Several types of tanks are used to store LNG in the world today. In some places a reinforced concrete tank surrounds the inner tank. Types of onshore LNG storage tanks include:

- Single containment tank,
- Double containment tank,
- Full containment tank,
- Membrane tank, and
- In-ground tank.

Single Containment Tank

A single containment tank is composed of an inner cylindrical container made of 9% nickel steel which is self-supporting (**Figure 1**; next page). This inner tank is surrounded by an outer tank made of carbon steel which holds an insulation material (usually an expanded mineral material called perlite) in the annular space. The carbon steel outer tank is not capable of containing cryogenic materials; thus the inner tank provides the only containment for the cryogenic liquid. However, single containment tanks are always surrounded by a dyke (bund or containment basin) external to the tank, either of which provides at least 100% secondary containment in the event of a complete failure of the inner tank. This type has an excellent history of reliability and represents the majority of tanks in the world but does require a relatively large area of land.

Double Containment Tank

The double containment tank is similar to a single containment tank, but instead of a containment dike there is an outer wall usually made of post-stressed concrete (**Figure 2**; next page). Therefore if the inner tank fails, the secondary container is capable of containing all of the cryogenic liquid.

The outer concrete wall increases the cost of the tank, but less space is required because there is no need for a containment dyke. Should the inner tank fail, the liquid will be contained and vapours will escape through the annular gap, which is the space between the two tanks or the tanks and the concrete wall.

Full Containment Tank

A full containment tank is a double containment tank in which the annular gap between the outer and inner tanks is sealed (**Figure 3**; page 4). The majority of LNG storage tanks built in the last 10 years worldwide have been designed as full containment tanks.

In this tank, the secondary container is liquid- and vapour-tight in normal operations. In case of leakage of the primary barrier, the secondary container remains LNG-tight. The secondary container wall is generally made of pre-stressed concrete and the roof is usually reinforced concrete, although under EN 1473 metal roofs may be allowed.

Membrane Tank

The membrane type of storage tank is a post-stressed concrete tank with a layer of internal load-bearing insulation covered by a thin stainless-steel corrugated membrane (**Figure 4**; page 4). In this design, the concrete tank supports the hydrostatic load (weight of the liquid) which is transferred through the membrane and insulation (in other words, the membrane is not self-supporting). The membrane is able to shrink and expand with changing temperatures.

These tanks were constructed primarily in France and Korea in the 1970's and 1980's.

In-ground Tanks

In-ground LNG tanks are obviously less visible in their surroundings (**Figure 5**; page 5). They are mainly used in Japan and some other Asian countries. They were developed by Tokyo Gas Engineering (TGE) in the early 1970's based on earlier designs in the UK, the US and Algeria and subsequently used by other Japanese companies. As of 2005, there were 61 in-ground storage tanks in Japan. The record for the largest LNG tank in the world was first set by an in-ground (200,000 m^3) although several above-ground tanks have recently been built with a similar capacity.

These tanks are more expensive and take longer to build than an above-ground tank – about 4 to 5 years compared to 3 years for a tank built above ground. The terminals with in-ground tanks are designed to harmonise with the surroundings and ensure safety at every stage of the lifecycle. These tanks do not need to be surrounded by a dyke or bund wall, so the separation distance from adjacent land is less than that of other types of tanks. This is especially important for countries such as Japan, Korea, and Taiwan. In 45 years, there have not been any incidents concerning LNG tanks which have had any impact beyond the terminal boundary.

Leak and Spill Capture

LNG terminals are designed to detect any vapour leaks, as well as to detect and capture liquid leaks. LNG containment is a system which consists of the primary containment in the tank plus secondary containment, e.g., the impoundment around the tank to capture and keep in place any leakage of LNG. Storage tanks also incorporate the following measures to prevent leaks or detect leaks immediately at the source:

- Tank construction of special materials and equipment with systems designed to safely insulate and store LNG at temperatures of -162°C (-259 °F);
- Cool down temperature sensors on the tank wall and base;
- Leak detection temperature sensors located in the annular space to signal a low temperature alarm;
- LNG tank gauging systems to provide remote readings and high/low level alarms;

- Level temperature density gauge to detect rollover potential;

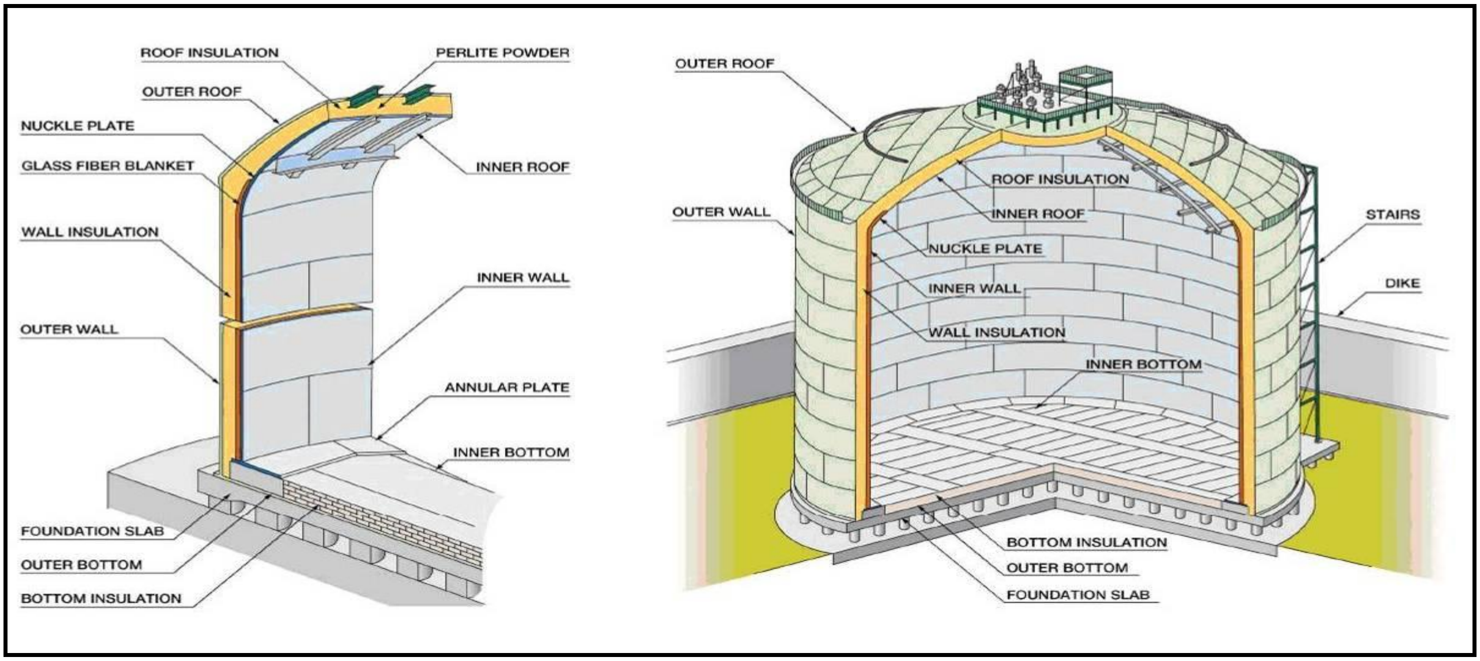
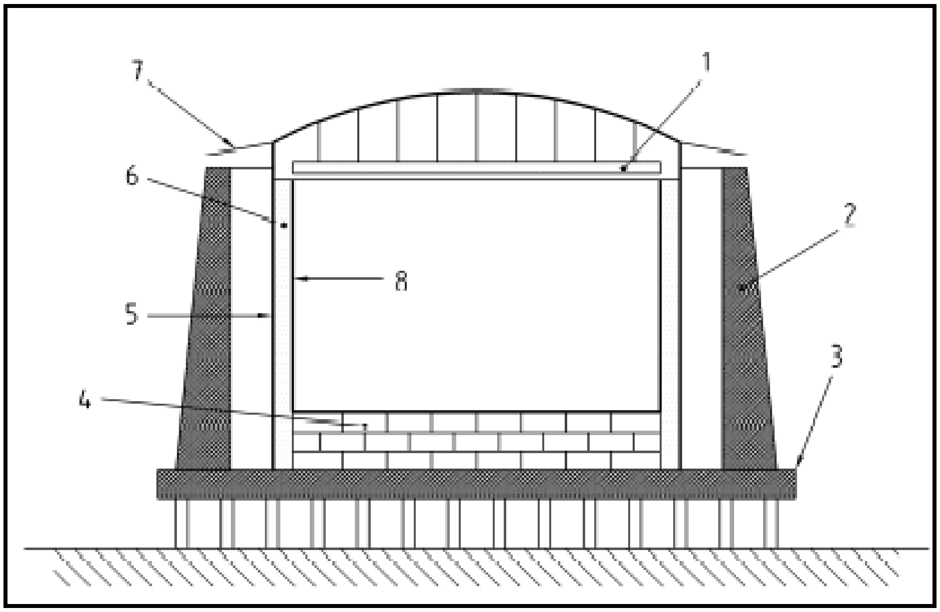


Figure 1. Single containment tank (Source: Kawasaki Heavy Industries, Ltd.)



Key

1 suspended deck (insulated)
2 post-stressed concrete secondary container
3 elevated slab
4 base insulation
5 outer shell (not able to contain liquid)
6 loose- fill insulation
7 roof if required
8 primary container

Figure 2. Double containment tank (Source: EN 1473)

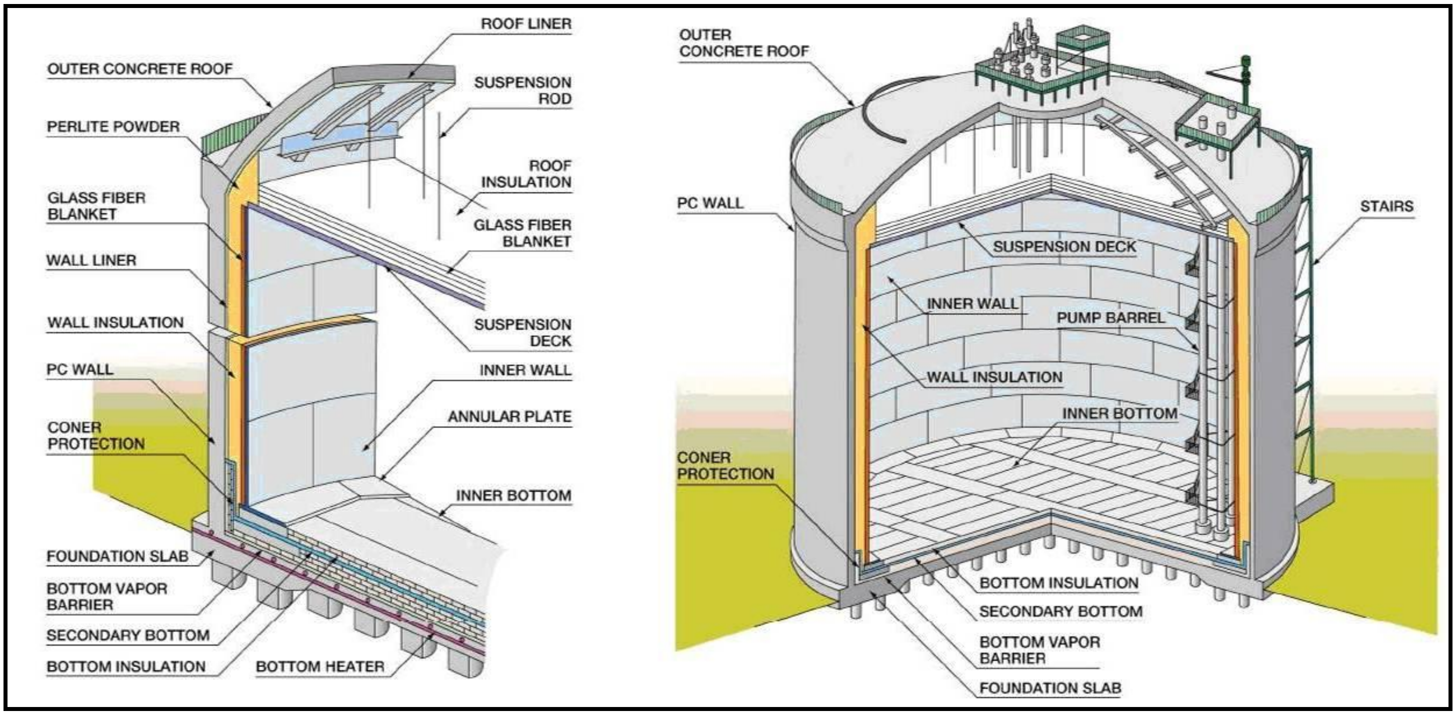
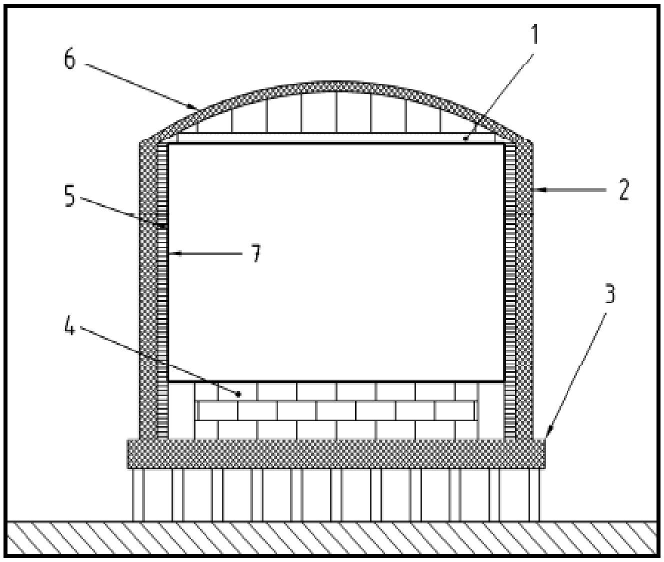


Figure 3. Full containment tank (Source: Kawasaki Heavy Industries, Ltd.)



Key

1	suspended deck (insulated)	4	base insulation
2	post-stressed concrete secondary container	5	loose fill insulation
		6	reinforced concrete roof
3	elevated concrete raft	7	primary container membrane

Figure 4. Membrane tank (Source: EN 1473)

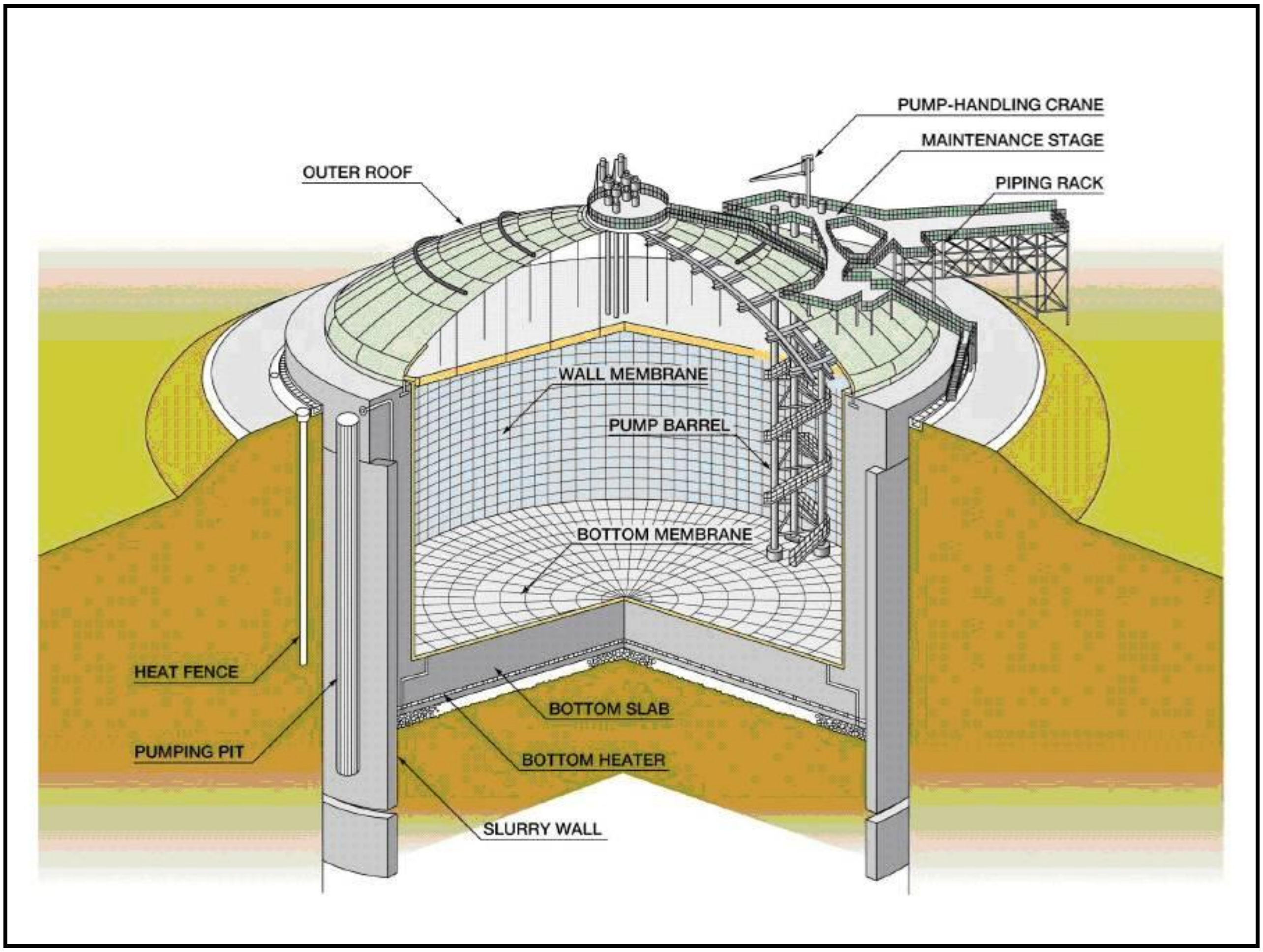


Figure 5. In-ground storage tank (Source: Kawasaki Heavy Industries, Ltd.)

- Pressure controllers and relief valves.
- Passive fire protection, e.g., fireproofing, fire resistant barriers and coatings; and
- Various codes and standards for maintenance and inspection of equipment in LNG service.

Many of these safety measures in tank design and construction were implemented to prevent a re-occurrence of the incident at a peak-shaving facility in Cleveland, Ohio, US in 1944, 20 years before LNG became a significant industry. Post-incident analysis clearly demonstrated that the size of the design of the capture basin was inadequate. Since then, codes and standards have been developed to require a second layer of protection around the primary containment (of single-containment tanks). Single-containment tanks now must be designed to prevent the spread of an LNG spill. Dykes, berms, and dam impoundments surround each single-containment storage tank to capture the LNG in case of a spill. The size of impoundment areas must be able to capture a volume which exceeds that of the storage tank. Dikes are designed to contain 100-110% of the tank volume and to be high enough so the trajectory of a leak at the upper liquid level in the tank can not overshoot the edge of the dike. Impoundment areas often have concrete or earthen liners and employ some method for extracting rain and deluge water.

In the unlikely event of a leak of any kind, all LNG facilities have many types of equipment to detect a release, and initiate immediate notification and control of the leak or spill. Standard detection and initial response equipment in various areas of an import terminal include:

- Cryogenic liquid detection;
- Gas or vapour detection;
- Smoke detectors;
- Flame detectors;
- Safety alarms;

- Emergency shutdown valves on piping to stop the flow of LNG and limit the quantity of LNG released; and
- Secondary containment designed to mitigate the consequence(s) of release.

Vapour and liquid detection equipment is used to detect, set off alarms and monitor flammable vapours. Most devices have remote monitoring screens, e.g., in a control room, and provide a safe and secure way to monitor the situation and manage the overall facility. Continuous improvements are made in detection systems and there are vendors who specialise in systems just for LNG.

LNG facilities develop and maintain emergency response plans for the unlikely event of any leak. These plans identify potential credible incident scenarios and then develop specific actions to control and mitigate the consequences of these incidents.

Key Points and Conclusions

In closing, the reader should remember the key points of this information paper:

1. In an industry in which safety considerations are paramount, as underscored by the degree to which related codes, equipment, regulations, procedures and systems permeate all of our efforts, containment is the primary requirement for LNG safety.
2. LNG facilities and terminals have more than one means of containment. Beyond the first layer (the specifically-designed and constructed tanks), various methodologies (including berms, dykes, impoundment dams and secondary tanks) are used to provide another layer of protection.
3. Various kinds of tanks are used around the world, including Single Containment Tanks, Double Containment Tanks, Full Containment Tanks, Membrane Tanks and In-ground Tanks.
4. Liquid and gas/vapour leak detection and response systems incorporate a wide array of relevant devices and technologies, including alarms, emergency plans and shutdown valves, fireproofing/fire-resistant barriers and coatings, flame detectors, gauging devices, pressure controllers, relief valves, smoke detectors and temperature sensors.
5. Most devices have remote monitoring screens, e.g., in a control room, to provide a safe and secure way to monitor the situation and manage the overall facility.

Next, in **Information Paper No. 6: Industry Safeguard Systems**, we will review leak prevention and detection systems, emergency plans and emergency preparedness in greater detail. This paper will touch upon again the profound importance of safety considerations in every facet of the LNG industry. As graphically reflected in the "Multiple Safety Layers" figure on the last page, these layers assure LNG safety, and are firmly based on a foundation of solid Industry Standards, Regulatory Compliance and Codes. These safety layers include several key components of the industry's Risk Management framework, including Primary and Secondary Containment, Control Systems which promote Operational Integrity; Protocols, Operator Knowledge and Experience (which are reinforced by comprehensive and ongoing training). A protective umbrella of Safeguard Systems, Separation Distances, and Contingency Planning, and Exercises further enhances the safe management of LNG.

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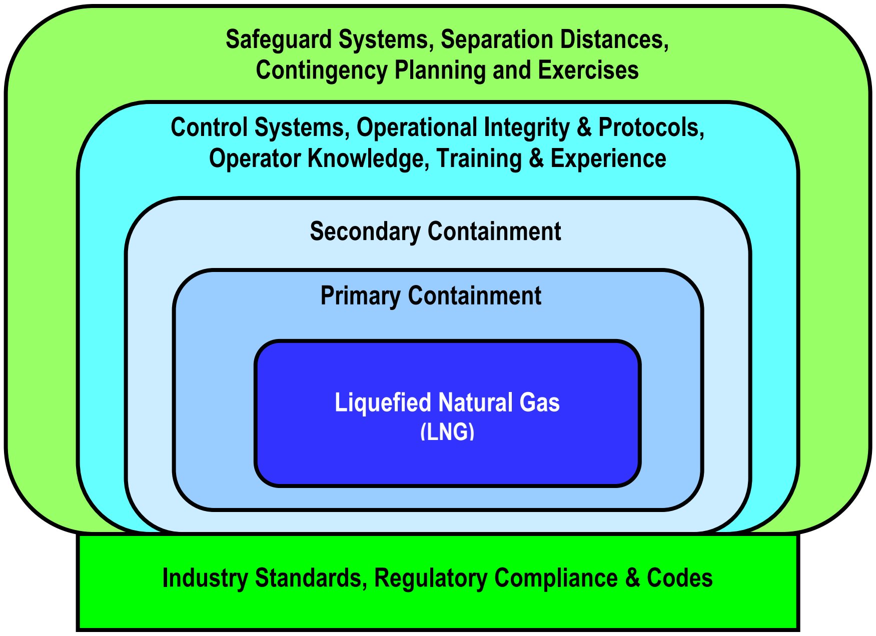
Multiple Safety Layers
Manage LNG Risk



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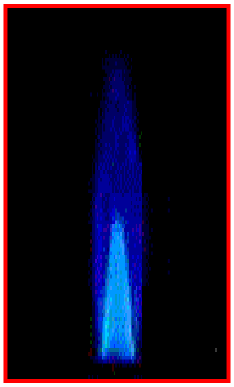
GROUPE INTERNATIONAL DES IMPORTATEURS DE GAZ NATUREL LIQUÉFIÉ

THE INTERNATIONAL GROUP OF LIQUEFIED NATURAL GAS IMPORTERS

LNG Information Paper No. 6



Managing LNG Risks – Industry Safeguard Systems

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GIIGNL's Technical Study Group has overseen the development of this Information Series of 7 papers to provide factual information about Liquefied Natural Gas (LNG). In French, Spanish, Portuguese, or Italian speaking countries, the abbreviation GNL is used in place of LNG. This paper describes the operational safeguards which the industry implements as standard practices to detect, control and minimize potential effects from a release of LNG. For more information on these topics, additional references and weblinks are provided at the end of this paper.

Safety Safeguards in Many Layers

The safety of LNG world-wide is the result of high industry standards, effective regulations, and a fervent industry commitment to rigorous risk management. Regardless of the type of LNG facility, there are multiple layers of protection implemented to minimise the likelihood of an LNG release. **Information Papers No. 4 and 5** describe ways in which the industry maintains operational integrity through regulations, codes, standards and best practices, and how the LNG is contained in various types of storage tanks. This paper describes industry safeguard systems designed to immediately detect, control and mitigate the consequences if a release of LNG were to occur in the import terminal.

There are two types of safety features in an LNG facility: management systems and equipment/technology systems. Management systems include studies during the design process which first identify hazards and then review the design to ensure that these hazards can be controlled or mitigated. During the operational phases, procedures are written to ensure that safe working practices are encouraged, inspections and maintenance are conducted in an appropriate and timely manner and that the impact on the public and employees of any unexpected circumstance is minimised.

With regard to safety equipment and technology, LNG facilities have multiple levels of hazard detection, mitigation and intervention systems. There are two types of intervention systems: those based on passive technology, which require no interaction, and active systems, where action is either automatic or an operator is prompted to take action.

Prevention

LNG facilities and LNG carriers are viewed in the industry as the "top of the line". This view is justly predicated on their high quality, robust safety systems and overall attention to detail in design, solid construction and stringent operational practices. All of these factors collectively serve to prevent accidents, incidents and product releases of any kind. The excellent safety record of the industry is substantive evidence of this commitment. There was a (single) major tank failure incident, which occurred in Cleveland, Ohio, US in 1944 at the beginning of the LNG industry, resulting in a fire and a number of fatalities. This incident is discussed in detail in **Information Paper No. 7.** At the time of the Cleveland incident, the safe storage practices required for cryogenic liquids were not fully understood. Since then, the LNG industry has implemented safety improvements to prevent situations which could lead to or cause such incidents.

Examples of standard practices which are now established around the world to prevent leaks and their escalation include the following:

- Compliance with known and proven codes and standards for designing and siting new facilities;
- Siting new facilities a safe distance from adjacent populations based on risk assessments;
- Construction of special materials and inclusion of systems designed to safely insulate and store LNG at temperatures of -162°C (-259 °F);
- Various codes and standards for maintenance and inspection of equipment in LNG service;
- Overpressure protection (pressure controllers and relief valves);
- Leakage detection and spill control through temperature probes;
- Ignition source control;
- Fire zoning;
- Emergency depressurising;
- Passive fire protection, e.g., fireproofing, fire resistant barriers and coatings; and
- Active fire protection.

Additional standard devices and practices specifically for tanks include:

- Cool-down temperature sensors on the tank wall and base;
- Leak detection equipment, e.g., temperature sensors, and low temperature alarms, located in the annular space;
- LNG tank gauging systems to provide remote readings, with high/low level alarms which trigger emergency shut down systems; and
- Combined temperature and density sensors to detect rollover potential.

In Europe, the Seveso II Directive requires a complete Safety Management System for the control of major-accident hazards. This System must include a safety study with a risk analysis and relevant measures for the mitigation of consequences. The final risk level must be acceptable to the authorities. In the US, the regulations generally require that these worst-case spill hazards are contained within the perimeter of the owner's property such that risk to the public is near zero.

Locating LNG facilities and vessels a safe distance away from adjacent industry, communities and other public areas provides the assurance of protecting citizens from potential hazards in case a serious incident occurs. In the current environment, where there is a threat of terrorism, the public is understandably concerned that bulk storage of a flammable energy source represents a risk. Separation of LNG from the public can take the form of exclusion zones for facility-siting or safety zones around LNG ships while underway. The separation distances used in codes, standards, and regulations are based on risk assessments and scientific analyses.

In addition to industry best practices and governmental requirements, financial institutions specify guidelines to assure that LNG facilities are safe and worthy of financing and insurance. The World Bank Group states in its guidelines that the layout of an LNG facility (and the separation distance between the facility and the public and/or neighbouring facilities outside the LNG plant boundary) should be based on an assessment of risk from LNG fire (entitled a "thermal radiation profile prediction"), vapour cloud ("flammable vapour cloud dispersion characteristic prediction"), or other major hazards. The results of such risk assessments define the recommended separation distance for a proposed facility. Generally in Europe, depending upon the design and storage capacity of the subject facility, risk assessments recommend a separation distance from residential, recreation areas, or other public built-up areas. In simple terms, separation distances ensure that the surrounding public is protected from the consequences of any credible LNG release at a terminal.

The industry standards and regulations described in **Information Paper No. 4** reduce the likelihood of a release. If a release were to occur, the consequence is minimised through the use of secondary containment and active safety mitigation systems described in this paper.

Figure 1 illustrates multiple layers of protective measures, for instance, to prevent the escalation of an LNG leak into a pool fire and to minimize the consequences of such an incident. The occurrence of a hazardous event, in this case, a pool fire, would require the simultaneous and very unlikely failure of several, independent layers of protection.

The layers of protection implemented at terminals include risk mitigation measures such as the following:

- **Spacing and design of pipes, equipment and storage tanks**: they must be made of specific materials in order to resist cryogenic temperatures and avoid LNG leaks. LNG tanks are equipped with integral impoundment.
- **Detectors**: Facilities are constructed with a variety of leak detection devices, including cameras, temperature sensors and various kinds of very specific detectors (for discovering fire, flame, gas, smoke or tank overfill). This detection equipment communicates to the control centre

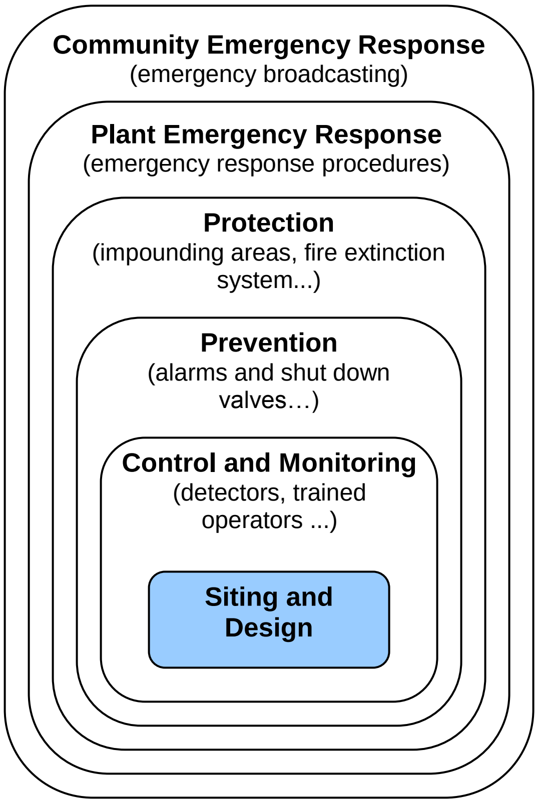

Figure 1: Layers of protective measures to prevent escalation of an LNG leak into a pool fire (Source: BV 2009)

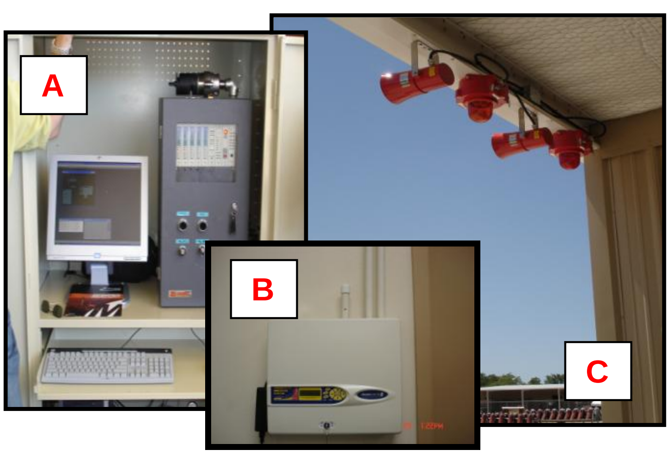

Figure 2. Detection and warning devices for LNG terminals: A) flame detection monitoring in a control room, B) aspirating smoke detector, and C) audible alarms (Photos provided by A.H. Walker)

and can automatically trigger emergency shut-down systems (some examples are shown in **Figure 2**).

- **Emergency shut-down (ESD) valves**: In case of fault detection, ESD valves are automatically closed to prevent the further loss of LNG.
- **Impounding areas**: In the event of an LNG leak, the spill is contained in these areas to control its spread, vaporisation rate and, if a pool fire occurs, to minimise the consequence outside the terminal.
- **Fire control systems**: LNG fires can be mitigated with fire-fighting systems available throughout the terminal.
- **Vapour reduction systems**: if an LNG pool has formed, foam generators can be used to reduce the rate of vapour formation and movement.
- **Trained operators**: operators are always present in the terminal to control operations and ensure rapid response to any emergency condition, including making emergency notifications to agencies and responders, as well as an emergency broadcast to the community.

Operations and maintenance personnel in LNG facilities are required to be trained, both initially and periodically thereafter, in:

- The hazards of LNG;
- The hazards of operation and maintenance activities;
- How to recognise breaches of security and execute security procedures;
- Understanding the potential causes, types, sizes and predictable consequences of fires and knowing and following fire prevention procedures;
- How to perform their assigned functions during both normal operations and emergencies; and
- How to provide first aid.

Verification of compliance with these requirements is performed by each national dedicated Authority.

Detection

Several systems incorporate monitoring and control devices to detect deviation from acceptable parameters, thereby enabling corrective action to prevent unsafe conditions. Standards and codes require that combustible gas detectors and low temperature detectors are located at places where an LNG release might occur and where LNG or low temperature vapour might accumulate. In Europe, the codes are: EN 1473. In the US, they are: NFPA 59A 49 CFR Part 193.2507, Subpart I and 49 CFR Part 127.201-3. These detectors are continuously monitored. They also have alarms set just above the detection levels and automatic shutdowns at hazard levels.

For facilities on land, monitoring systems are required by EN 1473 in Europe, and 49 CFR Part 193 and NFPA 59A in the US. Onboard ship, monitoring systems are required by the International Gas Carrier Code, the classification society's requirements and the USCG requirements of 46 CFR 153-154 and 33 CFR Parts 127, 160-169.

In addition to the code-required instrumentation specifically for leak detection, there is abundant normal process instrumentation which will alert an operator to an abnormal condition which may or may not be caused by leakage. Many areas are either covered by remote TV cameras or are visible to a plant operator or to a crew member from a ship's control room. An LNG release of any size is easily recognised visually, because of the condensation of water vapour from the atmosphere within any resulting cloud.

All LNG facilities have equipment to detect an LNG release and to initiate immediate notification so as to control the leak or spill. Vapour and liquid detection equipment is used to detect problems, set off alarms and monitor flammable vapours. Remote monitoring screens, e.g., in a control room, provide a means to instantaneously see the situation and manage the overall facility. Closed-circuit TV is used to monitor operational areas in the terminal and serve as a secondary visual system for the gas, flame, and fire detectors. Detection and initial response equipment includes:

- Cryogenic liquid detection.
- Leak detectors designed to detect low temperatures,
- Gas or vapour detection,
- Smoke detectors,
- Flame detectors,
- Safety alarms,
- Emergency shut down valves to limit the quantity of LNG released, and
- Secondary containment designed to mitigate the consequences of release.

Continuous improvements are made in detection systems.

Control and Mitigation

A hazardous event (e.g., a pool fire) could only occur due to simultaneous failure of several independent layers of protection.

If a liquid spill is detected, emergency shut-down valves may be automatically activated depending upon the situation, e.g., size of the spill and the location. They can also be activated manually by push buttons at the jetty, control room, around the terminal and on the LNG ship (when it is at the jetty). The emergency shut-down system stops all pumps and closes off all piping so that the LNG stays either in the storage tanks or on the ship if there is a ship offloading. In manyterminals, emergency-release couplings on the unloading arms, used to transfer LNG between the ship and the shore, are quick break-away lines that shut the unloading system down and allow the ship to move away from the jetty.

If a leak is detected, actions are taken to:

- Prevent fire by securing the leak and the area, eliminating ignition sources, and monitoring vapours until no flammable vapours remain;
- Warn and shelter facility workers and notify authorities as required or appropriate;
- Control vapour dispersion with foam and/or water curtains;
- Use water spray to increase the vaporisation rate of the LNG (rapidly warm it), which will facilitate a more rapid mixing and dilution of LNG vapours to outside flammable limits, and help them warm more quickly to the temperature at which they will become buoyant and rise away from ignition sources and people on the ground (**see Information Paper No. 1**); and
- Control and manage/mitigate incidents if vapours are ignited, using dry chemical powder or foam, and applying water to plant equipment (not the LNG fire) to cool it down.

High-expansion foam and water-spray curtains help control LNG vapours in a proactive manner. The application of foam to LNG spills on land, or water spills that are contained, e.g., in a storm drain or small pond, is an effective hazard control technique. Applying and maintaining a "blanket cover" of high-expansion foam can help to minimise ignition risk and/or to manage vaporisation rates and vapour dispersion, when either of these actions is appropriate for the specific situation. The use of water curtain sprays to form water barriers between LNG vapours and potential ignition sources can also be an effective risk mitigation technique for a liquid spill. Dry chemicals can be applied to extinguish flames if the vapours in a contained area ignite. High-expansion foam has proven effective in reducing flame height and radiant heat.

In the event of a leak or spill, responders wear personal protective equipment (PPE) while undertaking control and mitigation actions. Common PPE equipment in industrial operations includes safety goggles, steel-toed boots, gloves, and hard hats. In an LNG facility, PPE for protection from cold liquids and vapours, e.g., face shields suitable for contact with cryogenic materials, are also standard. During an LNG incident, additional personal protective equipment might include a breathing apparatus (depending upon the magnitude of any gas release), since LNG vapours can displace oxygen and lead to asphyxiation, along with fire protection gear such as:

- Full protective clothing (coat and trousers),
- Anti-flash hood,
- Fire helmet with visor,
- Fire gloves, and
- Fire boots.

Inspections

Government agencies routinely inspect LNG facilities and ships to verify that safety measures have been correctly applied and maintained. Inspections vary among countries, or regions. For example:

- **Europe**. The Safety Management System, required by the European Directive Seveso II and implemented by the operator, includes internal control loops for every safety activity. In addition, verification of compliance is made by oversight agencies and inspections are performed by local authorities.
- **US**. Safety activities and inspections are under the jurisdiction of several agencies: the US Coast Guard, the Pipeline and Hazardous Materials Safety Administration (PHMSA) of the US Department of Transportation, and the Federal Energy Regulatory Commission (FERC). All of these agencies inspect terminal operations after start-up. Each agency will verify safety compliance with their respective jurisdictions through inspections. The inspection rate is chosen by the responsible agency and will vary by facility.
- **Asia**. In Japan, the Ministry of International, Trade and Industry (MITI) prescribes inspection frequencies.

Emergency Response Plans

Being prepared for any emergency is an essential activity for LNG terminals and ships. A set of preparedness activities conducted before an incident helps assure that any incidents that do occur are well managed and mitigated. To be most effective, preparedness activities are conducted in a sequence, where the results of one activity leads into another, with the end result being that overall preparedness is constantly improving. This is referred to as the Preparedness Cycle (**Figure 3**). Preparedness is achieved and maintained through a continuous cycle of planning, organising, training, equipping, exercising, evaluating, and taking corrective action. Ongoing preparedness efforts among all those involved in emergency management and incident response activities ensure coordination during times of crisis.

Figure 3. Preparedness cycle (Source: US FEMA)

A good emergency response plan helps assure that responders have optimal control over an incident. Beginning to plan response actions at the time of an incident is an extra but avoidable challenge. For this reason, LNG facilities prepare and maintain emergency response plans which identify potential credible incident scenarios and then develop specific actions to mitigate the consequences of such incidents.

The regulations of countries, including the US and Europe, and companies, specify the content of these plans. For example, emergency response plans for import terminals, which in the US are required by FERC and must be approved before the terminal even begins operations, must include scalable procedures for responding to:

- Emergencies within the LNG terminal;
- Emergencies that could affect the public near an LNG terminal;
- Emergencies that could affect the public along an LNG vessel transit route;
- Methods for notifying agencies and the public; and
- Training and exercises using the plan.

It is important to involve all response stakeholders (including adjacent facilities) in the planning process to develop the plan. The facility emergency response plan is prepared in consultation with appropriate local and national governmental agency representatives, including first responder representatives. The valuable benefit of a plan is the planning process of working through incident management issues.

Another key component of emergency planning is the training of all emergency responders, which incorporates coordination, communication, drills and exercises. Hazards and mitigation scenarios are identified and used to develop responses and role assignments. Simulated emergencies, both table-top and full-scale, are used to validate the effectiveness and efficiency of both individual responders and responding organisations. Field exercises provide an opportunity to practice hands-on skills and cultivate expertise.

Participating in such training and exercises helps assure that the emergency response plan will be well understood by the organisations with responsibilities during an incident and that they are ready to respond effectively in the unlikely event of an emergency.

Key Points and Conclusions

In closing, the reader should remember the key points of this information paper:

1. Industry safeguard systems are designed to immediately detect, control and mitigate the consequences of any LNG release in an import terminal.

2. There are two types of safety features in an LNG facility: equipment/technology systems and management systems. The former include multiple levels of hazard detection, mitigation and intervention systems. The subject intervention systems may be active systems, requiring an operator to act or being automatically started, or passive systems, requiring no interaction.

   Management systems, include, among other things, studies during the design process which first identify the hazards and then review the design to incorporate steps which eliminate or control/mitigate the hazards. They also include, for example, the drafting, refinement and implementation/dissemination of sound operating procedures and safe working practices.

3. Safety design of facilities, systems, and equipment in the LNG industry are generally viewed as "top of the line", largely due to their high quality, robustness and implicit attention to detail.

4. The tragic accident in Cleveland, Ohio, US over 60 years ago, when LNG first became commercially viable, resulted in a fire and a number of worker and public fatalities. As a result of the exhaustive subsequent investigation, a comprehensive number of safety precautions have been implemented and are in effect throughout the industry.

5. Typical layers of protection implemented in modern LNG terminals are graphically illustrated in **Figure 1**. These layers begin, in a sense, with the Siting and Design of the terminal. The next layer reflects the Control and Monitoring features (including, for example, detectors and trained operators). Prevention components include alarms, shut-down valves, etc. Protection is provided by elements such as impounding areas and fire extinction systems. Company management of the incident is provided by implementing the Plant Emergency Response procedures. In addition, Community Emergency Response begins with notification about the leak or other incident, which activates governmental oversight, mobilises additional response resources to reinforce the facility's response, and thereby protects the public and adjacent properties.

The goal of this 7-paper series has been to identify and describe the many components which comprise LNG safety along with providing a global sense of LNG risk management. The figure on the last page graphically illustrates a comprehensive framework for LNG safety through "Multiple Safety Layers", which are all firmly based on a foundation of solid Industry Standards, Regulatory Compliance and Codes. These "safety layers" include: Primary and Secondary Containment, Control Systems which promote Operational Integrity, and Protocols, Operator Knowledge and Experience (which are reinforced by comprehensive and ongoing training). As demonstrated in this paper, a protective umbrella of Safeguard Systems, Separation Distances, and Contingency Planning further enhances the safe management of LNG.

The final paper in the series, **Information Paper No. 7**, presents commonly-asked questions and answers about concerning LNG import terminals.

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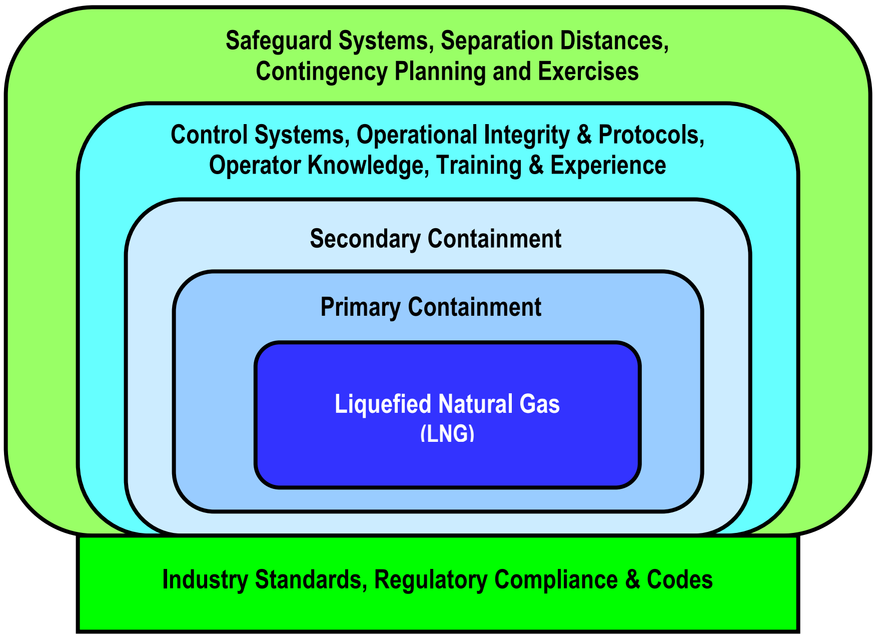
Multiple Safety Layers Manage LNG Risk



The GIIGNL Technical Study Group has developed this 7-paper series to provide public readers with factual information about the LNG industry's multiple layers of safety, as illustrated in the figure to the left.

The GIIGNL Information Papers include:

- No. 1 – Basic Properties of LNG
- No. 2 – The LNG Process Chain
- No. 3 – LNG Ships
- No. 4 – Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations
- No. 5 – Managing LNG Risks – Containment
- No. 6 – Managing LNG Risks – Industry Safeguard Systems
- No. 7 – Questions and Answers (Q&A's)

For more information about these and other topics, or to obtain copies of this report series contact:

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