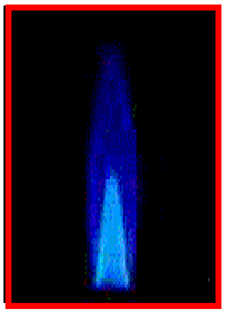
GROUPE INTERNATIONAL DES IMPORTATEURS DE GAZ NATUREL LIQUÉFIÉ
THE INTERNATIONAL GROUP OF LIQUEFIED NATURAL GAS IMPORTERS

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 prerequisite 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 (MSDSs). [Click here to View MSDS.]

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, 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 when under moderate pressure (less than

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 Hydro-carbons	Various	Trace	Trace

1.5 MPa or 200 psi). In the US, Canada, and Japan, LPG consists primarily of propane (**Table 2**). 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, 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 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).

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.

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.

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

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.

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 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**.

For a relative humidity 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 of approximately -110°C/-166°F, the relative density of the natural gas will become less than 1 and the vapours become buoyant.

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)

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 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.

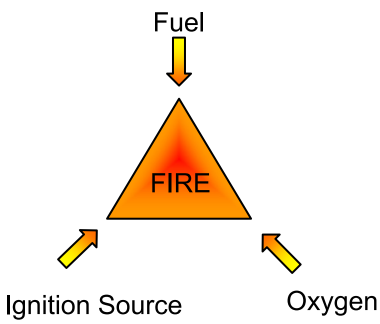


Figure 3. The fire triangle

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**).

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

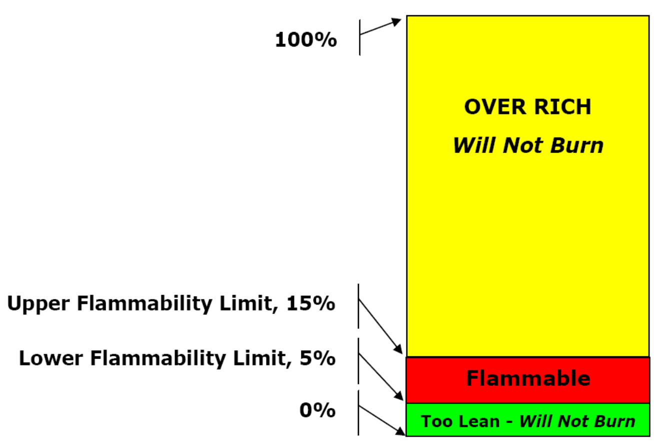


Figure 4. Flammability range for methane (Source: Foss 2003)

limits to assure safe handling and use. Materials that 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 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**.

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

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 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.

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

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 of other hydrocarbons. The specific chemical composition of 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 and 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, Contingency Planning and Exercises 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.

References and Additional Resources

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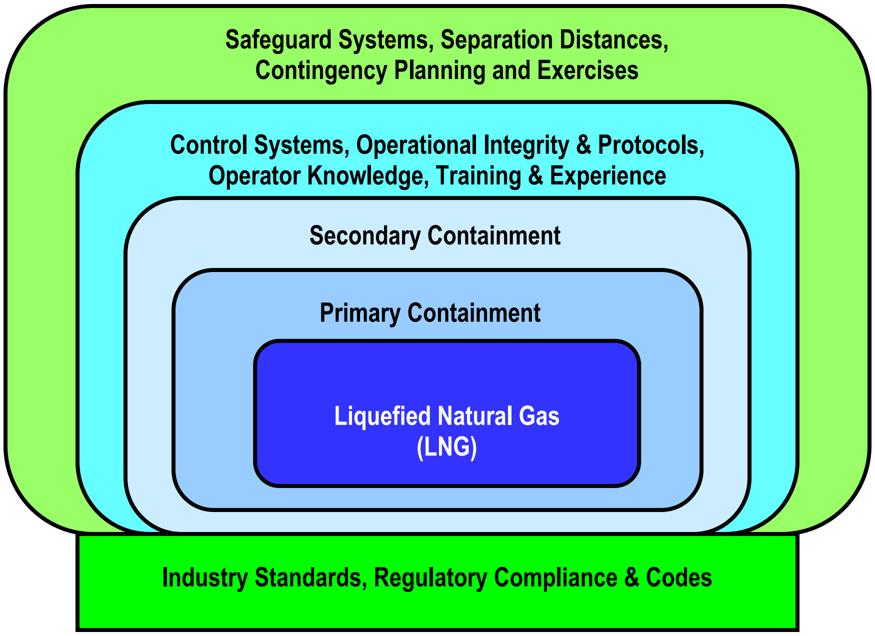
Multiple Safety Layers Manage LNG Risk



(Source: SEA Consulting, Inc.)

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 beyond the foundation of industry standards, regulatory compliance and codes 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&As)

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