LNG INFORMATION PAPER

#1

2019 Update

Basic Properties of LNG

contents

GIIGNL's Technical Study Group introduces a series of Information Papers that provide factual information about Liquefied Natural Gas (LNG). This paper begins with a review of basic properties of LNG, which is a pre-requisite for accurately assessing potential LNG safety hazards and risks.

INTRODUCTION

A basic knowledge of LNG must begin with an examination of its chemical and physical properties because the properties that make LNG a good source of energy can also make it hazardous if not adequately contained. These properties determine how LNG behaves, inform 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". This is because such specifics matter and universal generalisation about LNG are often inexact and inappropriate. Inaccurate information about the properties of LNG that influence potential safety hazards can lead to misunderstanding and confusion. For example, when thinking through how LNG would behave if accidentally or intentionally released (e.g. from a terrorist attack), the outcome will 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 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 (-148°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 Oymyakon (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. It may also have a smell due to an odorising substance 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

These properties are listed on Material Safety Data Sheets (MSDS's).

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.

Table 1. Examples of LNG composition

Origin	Nitrogen (N_2X)	Methane (CH_4) C1 %	Ethane (C_2H_6) C2 %	Propane (C_3H_8) C3 %	Butane (C_4H_{10}) C4+ %	Gas GCV MJ/m³ (n)	Wobbe Index MJ/m³ (n)
Australia NWS	0.04	87.33	8.33	3.33	0.97	45.32	56.53
Malaysia Bintulu	0.14	91.69	4.64	2.60	0.93	43.67	55.59
Nigeria	0.03	91.70	5.52	2.17	0.58	43.41	55.50
Qatar	0.27	90.91	6.43	1.66	0.74	43.43	55.40
Trinidad	0.01	96.78	2.78	0.37	0.06	41.05	54.23

(Source: 2018 Annual Report, GIIGNL)

Due to its chemical composition, natural gas is the cleanest burning hydrocarbon, which offers a considerable chance to reduce CO_2 emissions. It produces the least CO_2 of all fossil fuels because of its high heating value, low carbon content and efficient combustion. When natural gas is used for electricity generation, it produces 45-55% less greenhouse gas (GHG) emissions than coal and 20% less than oil. Natural gas is also one of the keys to solve the global air pollution problem as it emits virtually no sulphur or particles.

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 1.5 MPa or 200 psi). In the U.S., 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 at ambient (room) temperatures, whereas LNG is stored as a liquid only at very low temperatures and ambient pressure.

Table 2. Typical composition of LPG in % by volume

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.*

BOILING POINT

Boiling point is one of the most significant properties because it defines when gas becomes a liquid. Merriam-Webster online (www.merriam-webster.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.

The liquefaction process cools natural gas to a temperature below its boiling point, changing it to a liquid with a volume approximately 600 times lower than that occupied by the gas. Before distribution to industrial and residential consumers LNG is converted back into natural gas (regasified) by warming it back above its boiling point.

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

Table 3. Boiling points of water and some common gases

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

(Source: Adapted from the Engineering Toolbox online, www.engineeringtoolbox.com/boiling-points-fluids-gases-d_155.html)

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.

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 420 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 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 at ENGIE Lab CRIGEN LNG testing facility *(Source: Engie Lab)*

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

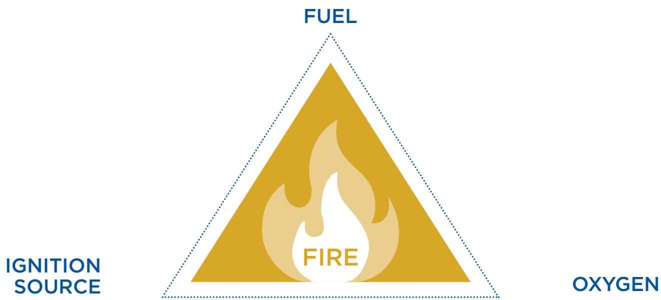
Three things are needed to support a fire:

- 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 Flammability Limit» (LFL) and the «Upper Limit» (UFL) (**Figure 4**).



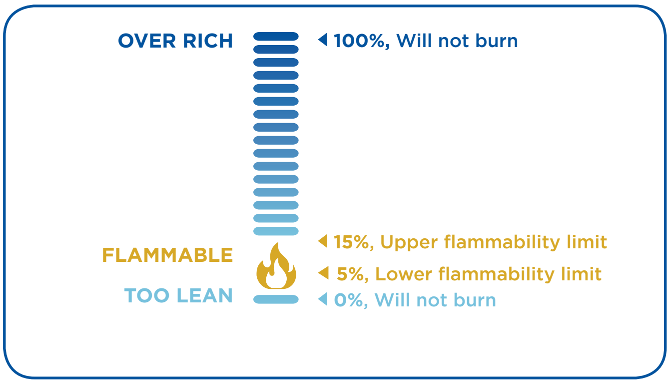


Figure 4. Flammability range for methane

(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 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.

Table 4. Flammability limits of hydrocarbon fuels

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

(Source: NPFA Fire Protection Handbook)

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.

Table 5. Auto-ignition temperature of some fuels at standard conditions

	NATURAL GAS	DIESEL OIL	GASOLINE
Auto-ignition temperature	599°C	260-371°C	226-471°C

(Source: BV 2009)

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.

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 of the public.

KEY POINTS AND CONCLUSIONS

In closing, the key points of the first information paper are:

1. First, and most importantly, one must understand that those properties which make LNG a good source of energy can also make it hazardous if not adequately contained. While LNG is predominately methane (about 85%-99%), its composition also includes small amounts 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 or 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.

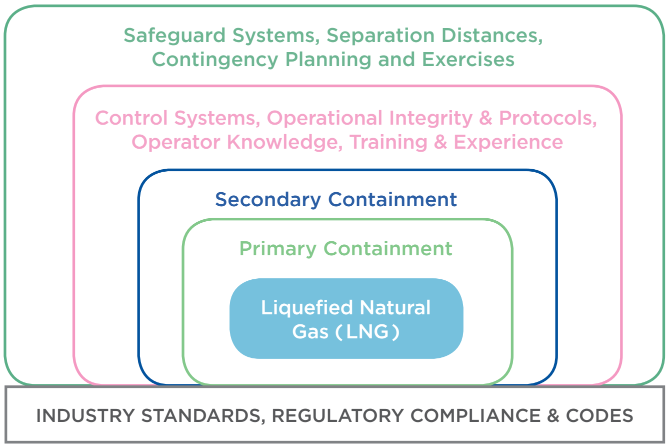
5. LNG is odourless, colourless, non-corrosive, non-flammable and non-toxic.

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.

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 below.

Multiple Safety Layers Manage LNG Risk



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GIIGNL
8 rue de l'Hôtel de Ville
92200 Neuilly-sur-Seine (France)
Telephone: +33 (0)1 56 65 51 60 Email: central-office@giignl.org
Web address: https://giignl.org