

## Attachment 1. LNG Safety

Commercial liquefied natural gas (LNG) has been produced, transported and used around the world for 45 years. At January 2007, 23 LNG export (liquefaction) terminals, 58 import (re-gasification) terminals, and 224 LNG ships were in operation, altogether handling approximately 168 million metric tons of LNG every year (Foss et al., 2007). An additional 21 LNG carriers, all but one above 140,000 m<sup>3</sup> capacity, were delivered in 2007 (BS Energy Services, 2007).

### 1. Properties and Hazards of LNG

LNG is composed mostly of methane. Foss et al. (2003) summarise the properties of LNG thus:

LNG itself poses little danger as long as it is contained within storage tanks, piping, and equipment designed for use at LNG cryogenic conditions. However, vapours resulting from LNG as a result of an uncontrolled release can be hazardous, within the constraints of the key properties of LNG and LNG vapours – flammability range and in contact with a source of ignition.

LNG has a higher flammability range in air (Table 1.1) and a higher auto-ignition temperature than other liquid fuels (Table 1.2). The upper flammability limit and lower flammability limit of methane, the dominant component of LNG vapour, are 5% and 15% by volume, respectively. When fuel concentration exceeds its upper flammability limit, it cannot burn because too little oxygen is present. This situation exists, for example, in a closed, secure storage tank where the vapour concentration is approximately 100% methane. When fuel concentration is below the lower flammability limit, it cannot burn because too little methane is present. An example is a leak of a small quantity of LNG in a well-ventilated area. In this situation, the LNG vapour will rapidly mix with air and dissipate to a concentration of less than 5%.

**Table 1.1 Comparison of properties of liquid fuels**

Properties	LNG	LPG	Petrol	Fuel Oil
Toxic	No	No	Yes	Yes
Carcinogenic	No	No	Yes	Yes
Flammable vapour	Yes	Yes	Yes	Yes
Forms vapour clouds	Yes	Yes	Yes	No
Asphyxiant	Yes, but in a vapour cloud	Same as LNG	Yes	Yes
Extreme cold temperature	Yes	Yes, if refrigerated	No	No
Other health hazards	None	None	Eye irritant, narcosis, nausea, others	Same as petrol
Flash point* °Celsius (°F)	-188 (-306)	-144 (-156)	10 (-50)	60 (140)
Boiling point °Celsius (°F)	-160 (-256)	-42 (-44)	32 (90)	214 (400)

**Table 1.1 (cont'd) Comparison of properties of liquid fuels**

Properties	LNG	LPG	Petrol	Fuel Oil
Flammability range in air, %	5 to 15	2.1 to 9.5	1.3 to 6	N/A
Stored pressure	Atmospheric	Pressurised (atmospheric if refrigerated)	Atmospheric	Atmospheric
Behaviour if spilled	Evaporates as visible clouds, parts of which could be flammable or explosive (if contained) under certain conditions.	Evaporates, as vapour clouds which could be flammable or explosive under certain conditions.	Evaporates, forms flammable pool; environmental clean up required.	Same as petrol

Source: after Foss et al. (2003)

\* 'Flash point' means the minimum temperature at which a liquid gives off a vapour within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid (OSHA, 2008).

**Table 1.2 Auto-ignition temperature of liquid fuels**

Fuel	Auto-ignition Temperature, °Celsius (°F)
LNG (primarily methane)	540 (1,004)
LPG	454 to 510 (850 to 950)
Ethanol	523 (793)
Methanol	464 (867)
Gasoline	257 (495)
Diesel	316 (Approx. 600)

Source: after Foss et al. (2003)

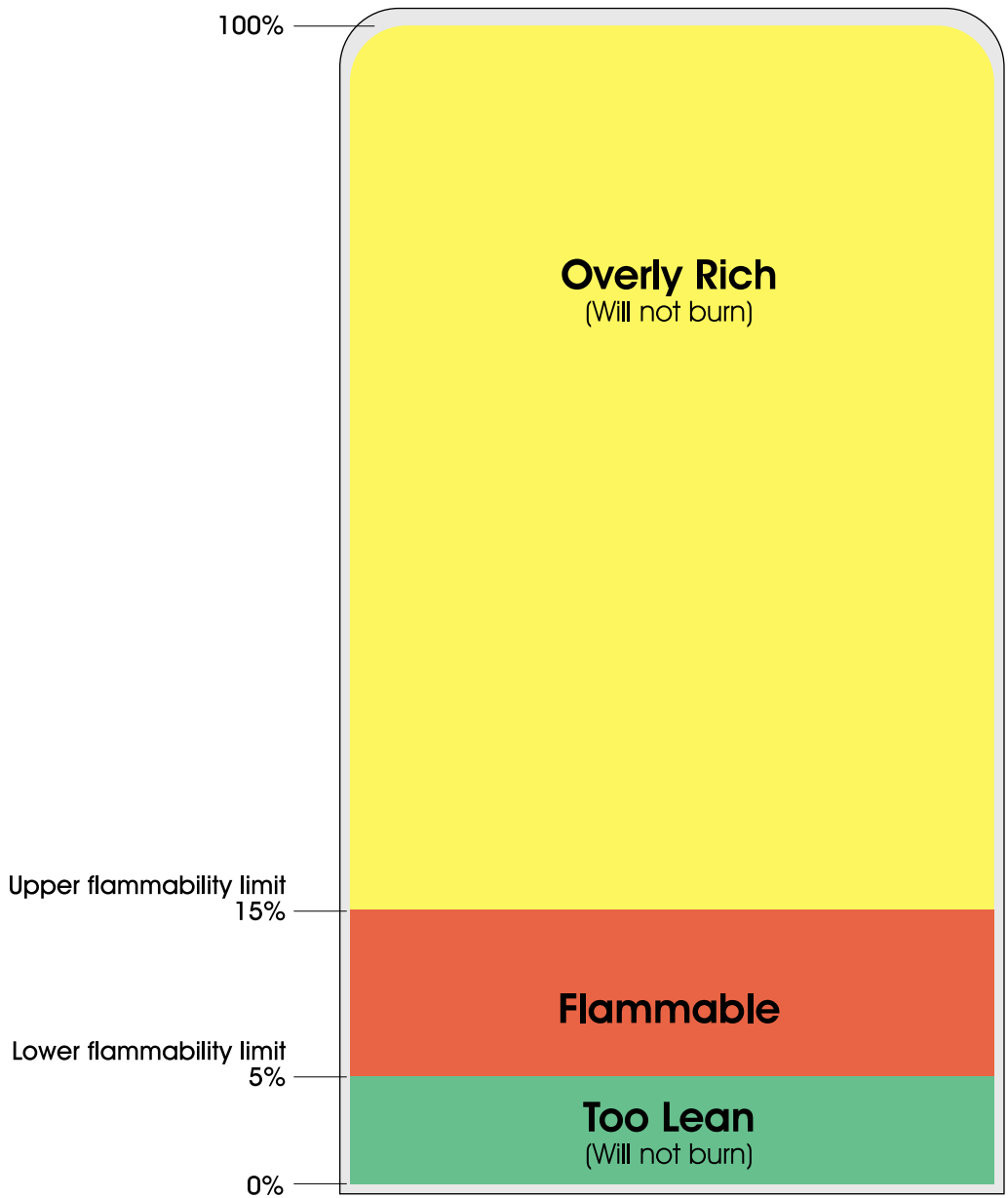
LNG is also intrinsically less explosive than other liquid fuels:

- Methane has a narrow flammability range outside which it cannot burn (Figure 1.1).
- LNG is stored and transported at atmospheric pressure, so unless LNG is under pressure (for example, being pumped through a pipe), it will flow and evaporate if the containing vessel leaks, rather than escape as a rapidly expanding vapour cloud. LNG spilled in the open is therefore slow to mix with air into a combustible concentration. If ignited, therefore, spilled LNG will tend to burn only at the evaporating edges of the pool. The spilled LNG itself cannot burn.


Specific conditions are required for the presence of LNG to lead to an explosion:

- An ignition source.
- Vapour within the flammability range (a methane concentration in air of between 5% and 15%; see Table 1.1).
- Containment of the vapour cloud in a confined space, such as a building or vessel.

If only the first two of these three conditions are fulfilled (for example, if LNG ignites after escaping into the open air as a gas, spill or pressurised stream), the released gas will only ignite at the edges of the spill (where the methane concentration in air is within the 5% to 15% flammability range).



Source:  
Foss et al., 2003.

	Job No: 1284	Esso Highlands Limited	Flammable range for methane (LNG)	Figure No: <b>1.1</b>
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Similarly, when spilled pools of LNG ignite, the resulting fire will occur at the edges of the evaporating vapour cloud. The thermal flux (heat) will be larger for a larger pool of spilled LNG, but not in direct proportion, because combustion is constrained by the rate at which the methane can mix with air. Moreover, the larger the spill, the harder it becomes for the gas to mix with air in the flammability range, so combustion is impeded. This incomplete combustion, in turn, means that the thermal flux of a small-spill fire cannot be simply scaled up in proportion for a larger spill (Beale, 2007). At the same time, a burning pool of LNG can be impossible to extinguish; and the larger the spill, the longer it will burn. (The fires after the accident at the Skikda LNG facility in January 2004, discussed in Section 3, burned for eight hours.)

A stream of LNG could escape from high-pressure parts of the circuit, in particular when the LNG is being pumped. If there is an ignition source, the evaporating gas at the edges of the stream will burn in a process known as a 'jet fire'.

## **2. Incidents**

Table 2.1 lists the five fatal LNG incidents that have occurred since 1944 and their consequences. The low total number of incidents over this 64-year period reflects the growing experience and improved safety performance of the industry. This record of improvement was marred by the 2004 fire and explosion at the Skikda LNG facility in Algeria, where the section of the plant that failed was scheduled for decommissioning and lacked standard contemporary safety equipment.

**Table 2.1 Fatal LNG Incidents 1944 to present\***

Year	Facility	Fatalities	Damage	Notes
1944	East Ohio Gas LNG Tank, Cleveland, USA	128 (50 employees, 78 residents)	NA	Tank made from low-nickel steel failed under cryogenic temperatures; no bund around tank. Vapour cloud formed and was blown by the wind into the surrounding streets and stormwater system. Natural gas in the vaporising LNG pool ignited.
1977	Arzew, Algeria	1 employee frozen to death	NA	Aluminium valve failure on contact with cryogenic temperatures. Wrong aluminum alloy on replacement valve. LNG released, but no vapour ignition.
1979	Columbia Gas LNG Terminal, Cove Point, Maryland, USA	1 employee	Yes	Explosion within an electrical substation. LNG leaked through LNG pump electrical penetration seal, vaporised, passed through 60 m of underground electrical conduit, and entered the substation. No gas detectors in the substation building as natural gas was never expected. The normal arcing contacts of a circuit breaker ignited the natural gas and air mixture, resulting in an explosion.
1983	Bontang, Indonesia	3 employees	Yes	LNG Train B ruptured when a blind flange left in a flare line during start-up caused an overpressurisation three times greater than the design pressure. All the pressure-protection systems were connected to this flare line. Debris was projected some 50 m and killed three workers. The ensuing fire was extinguished in about 30 minutes. This incident occurred during dry-out and purging of an exchanger with warm natural gas prior to introducing LNG into the system (no LNG was involved or released).
2004	Skikda LNG Facility, Algeria	27 employees	Explosions and fire destroyed part of the LNG facility. Storage tanks not damaged.	Hydrocarbon refrigerant vapour leaked into a steam boiler inlet. The boiler overheated and ruptured close enough to the gas leak to ignite the vapour cloud in a confined space and hence cause an explosion. A U.S. government report found local ignition sources, a lack of 'typical' automatic equipment shutdown devices, and a lack of hazard detection devices contributed to the incident.

Source: after Foss et al. (2003).

\* Excludes industrial accidents unrelated to the presence of LNG, such as Texas Eastern Transmission LNG Tank, Staten Island, NY, USA, 1973 (empty tank repair accident, 40 fatalities).

Improvements in the planning, design and operations of LNG facilities reflect lessons learned from past mistakes. More recently; however, a lower public tolerance to risk (and concerns about what has not happened but some believe could happen) has maintained pressure for ever-stricter safety criteria. Much of the concern arises from scenarios that have a low probability of occurring but high consequences if they should occur (Box 2.1). Since the accident rate in the industry has remained low, the recent strengthening of safety criteria has necessarily been based on modelling of possible hazards.

**Box 2.1 Note on extreme LNG accident scenarios**

*Although the LNG industry has a strong safety record, the public's lack of familiarity with LNG and the many design and safety precautions that are in place for its storage and use has contributed to the general concern many feel about LNG siting. Many individuals are unaware of the large improvements in engineering design and best practices that help ensure the safe handling of LNG, which makes it easier for them to believe extreme scenarios that are unlikely given today's design and practices.*

*Opponents often put forth two types of scenarios:*

- Scenario 1: An LNG tanker releases its LNG all at once in a cataclysmic failure (accidental or by terrorist action).*

*In fact, LNG tankers use multiple tanks to limit the amount of LNG that can be released at one time. The detailed analysis recently completed as a part of the Sandia report provides further evidence that, while it is possible for multiple tanks to fail as a result of terrorist attacks or some very unlikely accidental cause, the simultaneous failure of all the tanks on a tanker is not considered credible.*

- Scenario 2: A vapour cloud from released LNG envelopes a populated area, ignites, and then explodes.*

*An LNG vapour cloud needs both some degree of confinement and a strong ignition source to create an explosion. LNG releases that encounter strong ignition sources are far more likely to result in vapour cloud fires than they are in explosions.*

*Nevertheless, there are hazards with the transport or storage of large quantities of any flammable material, and terrorists unfortunately have demonstrated that even a small quantity of flammable material can lead to major consequences. It is important to ensure that facilities handling large quantities of any hazardous substance follow the best practices and regulations to minimise risks and promote safety.*

*The Sandia study made two compelling conclusions:*

- Risks from accidental LNG spills, such as from collisions and groundings, are small and manageable within current safety policies and practices.*
- Risks from intentional events, such as terrorist acts, can be significantly reduced with appropriate security, planning, prevention, and mitigation.*

*Source: after IFC (2005), citing Sandia (2004).*