# Liquefied Gas Terminals – Designed with Safety at Heart

Karina Almeida Leñero, Senior Safety Engineer, TGE Gas Engineering GmbH, Mildred-Scheel-Str. 1, 53175 Bonn, Germany.
Richard Collitt, Principal Process Engineer, TGE Gas Engineering GmbH UK Branch, Suite 2a, MIOC, Styal Road, M22 5WB Manchester, UK.
Sarah Fiedler, Process Engineer, TGE Gas Engineering GmbH, Mildred-Scheel-Str. 1, 53175 Bonn, Germany.
Yet Th ng Lee, Senior Process Engineer, TGE Gas Engineering GmbH UK Branch, Suite 2a, MIOC, Styal Road, M22 5WB Manchester, UK.

The past decade has seen a significant increase in the number of liquefied gas terminals coming online. These can range from relatively simple storage facilities for chemical plants, to complex logistic hubs with loading and unloading of marine vessels, bunkering, truck and rail loading operations as well as regasification to supply gas to national gas networks. These operations require multiple interfaces between plant operators and external parties. The safety of these terminals depends on a number of factors including their design and operational philosophy. A design that is informed by a thorough understanding of the inherent hazards and their potential consequences can greatly decrease the risk posed by the storage and handling of large amounts of flammable materials.

In order to achieve safety, efficiency and reliability in terminal operation, a multi-disciplinary approach is required, with process safety an integral part of the plant design process.

This paper presents an approach to the design and construction of terminals handling liquefied gases (e.g. LNG, ethane, ethylene, propane). Projects start with the identification and evaluation of major hazards in close collaboration with the plant design and layout team. This approach can minimise the risk of escalation and any potential effects outside the terminal boundaries. The hazards are re-evaluated as the design progresses and, where required, mitigation measures are put in place.

This paper will show how the above principles have been applied to numerous projects around the world, with examples of solutions for designing and building liquefied gas terminals that are cost effective, energy efficient and based on sound environmental and safety engineering principles.

Keywords: Design Safety, Hazard Assessment, LNG, Cryogenic storage

## 1.0 Introduction

The first large scale liquefaction of natural gas took place in the USA during the 1910s, when natural gas was liquefied in order to extract helium, which was intended for use in British dirigibles. Commercial LNG production only started in the 1940s in Cleveland, Ohio. The plant operated successfully for 3 years, until a cylindrical tank rupture in 1944 and the resulting fire caused 130 fatalities (LNG Fire Protection & Emergency Response, 2007). This early incident highlighted the need for safe operation and delayed the construction of further LNG facilities until better construction and insulation materials were available.

Today, the LNG trade volume is over 290 MT per annum and is showing rapid growth. Only 19 countries in the world export LNG (International Gas Union, 2019), with the market share dominated by Qatar (27% in 2017). By contrast, 40 countries import LNG. This has led to an increase in the number of liquefied gas terminals in operation, all of which need to operate reliably and safely.

In this paper we present a holistic approach to ensuring the safety of liquefied gas installations. The safety design is based on hazard assessment, as recommended in international standards such as EN1473. The hazards assessment cycle is at the heart of the design process: hazards are identified and their impacts are evaluated, which may involve consequence modelling. This in turn guides the selection of the required control and mitigation measures to ensure that the overall terminal design is safe with sufficient barriers to deal with the foreseeable hazardous scenarios, while remaining efficient and cost effective.

In the following sections we will explore our approach: first through general themes such as design and layout, then through a detailed examination of the main plant components and processes and finally through an exploration of fire safety measures in the event of a loss of containment.

# 2.0 General considerations

## 2.1 Safety Design

Projects start with the identification and evaluation of major hazards in close collaboration with the plant design and layout team. This approach helps to identify any risk of escalation early and thus provides ample opportunities to mitigate the credible accident scenarios.

At the outset of the project, it is important to identify the major hazardous scenarios that could result in catastrophic escalation and intolerable effects both inside and outside the plant. This is achieved through consequence modelling based on experience with the design of similar terminals. It is vital to consider the terminal surroundings and identify any sensitive receptors such as schools, hospitals or places where people congregate. At this point in the design process, it is possible to suggest changes to the layout to reduce the risk of escalation.

During the engineering phase of the project, several studies and reviews are undertaken to ensure the safe design of the facility. These studies aim to identify the potential hazards introduced by the terminal and particular vulnerabilities due to the location, technology selected, or substances being handled, and then consider the potential effects on people, environment and assets. Among others, the following studies are performed:

<u>Hazard Identification Study (HAZID)</u>

This is often the first step of the process to understand and assess the effects of the project on safety and the environment. The result of this study is the identification of different types of hazards that exist on the facility. Some hazards exist singly, while some are present in combination with other hazards.

<u>Physical Effects Modelling</u>

This evaluates the impacts of loss-of-containment scenarios (e.g. dispersion of flammable and toxic substances, fire and explosion overpressure) on sensitive receptors (for example schools or hospitals or structures whose failure would lead to catastrophic escalation).

<u>Hazard and Operability Study (HAZOP)</u>

This is a qualitative study that examines the process in a structured and systematic way to identify and evaluate risks to personnel, the environment and equipment arising from the plant operations. The intention is to identify design or engineering issues that may not otherwise have been found. For this reason, it is executed by a multidisciplinary team and is based on the experience and knowledge of the participants.

<u>SIL (Safety Integrity Level) Assessment:</u>

Safety Instrumented Functions (SIF) provide an extra protection layer to bring the process to a safe state in case the Process Control System (PCS) fails to keep the process parameters within the safe operating envelope. Once the required Safety Instrumented Functions have been identified, a SIL assessment is performed to determine the required reliability of each SIF.

<u>Safety Design Peer Review</u>

This review at the end of the detailed design phase is intended to ensure that all hazards analysed in the previous studies have been addressed and that sufficient control and mitigation measures are in place to ensure that the terminal can be safely operated according to the design intent. It should also act as a check-point to ensure that the required documentation is ready before proceeding to the project execution phase.

The above approach allows an optimal implementation of control and mitigation measures to reduce the safety and environmental risks to tolerable levels.

One of the challenges faced by an EPC contractor (Engineering, Procurement, Construction) is that commonly the location selection is outside its control. In many cases, the client has pre-selected the terminal/plant location based on land availability and/or logistics considerations and the potential impacts of the new facilities on the surroundings are not fully considered or only partially understood. During a preliminary safety assessment, the potential for off-site impacts (i.e. presence of flammable gas, thermal radiation and/or explosion overpressure) is analysed and measures to mitigate them are proposed. When available, the potential impacts of surrounding facilities on the new plant are also considered, but this often remains an area of uncertainly as the information is limited.

## 2.2 Layout

A good plant layout is critical for the safety of process plants. Effective use of space is considered for the arrangement of the facilities inside the terminal. The layout design considers aspects such as escape routes, access for fire-fighting, environmental issues, maintenance requirements and accessibility, optimised interconnecting piping lengths between units, operational flexibility, future extensions of the terminal and construction constrains.

When developing the plant layout, it is important to identify and analyse scenarios that could result in escalation or lead to consequences outside the plant boundaries. Sufficient separation is required between the hazard and sensitive receptors to prevent harm to people and minimise the risk of escalation, and sufficient separation distance is indeed the best mitigation measure to avoid escalation. Separation distance is particularly important for fluids more reactive than LNG, like propane or ethylene, which can lead to very high explosion overpressures. However, sufficient separation distance is not always achievable, as available land is often constrained, or if an existing facility is being extended.

When applicable, minimum safety distances are based on codes and standards, but in many cases there is scope for optimisation based on hazard analysis, which includes physical effects modelling to understand the consequences of common leak scenarios and the resulting effects (i.e. gas dispersion, thermal radiation and explosion damage).

Other typical layout considerations and safety measures are listed below (the values quoted here are recommendations taken from EN 1473, API 521 and company experience):

- To limit the maximum potential explosion overpressures, it is good practice to separate large congested areas into smaller ones, with an appropriate safety gap. A separation distance of 9.1m (30 ft) has been suggested in the literature (Alderman, 2014; see also CCPS guidelines, 2010).
- To minimise the risk of escalation due to structural failure as a result of fire, the maximum incident radiation on concrete structures should be 32 $kW/m^2$. On a steel tank or structure this should be no more than 15 $kW/m^2$.
- It is often the case that structures outside the plant have little or no protection against fire. Therefore, radiation outside the plant boundary should be limited to 5 $kW/m^2$.
- As far as possible, equipment is located so that major sources of release are located away from the plant boundary but also away from congested areas in the plant, in order to avoid escalation within the plot. However, the pipe routing design should follow a logical process flow to avoid unnecessary lengths of piping.
- Where necessary, equipment, buildings or structures are located such that the impact of external hazardous operations upon the terminal facilities is minimised.
- Vehicular access should be considered. For example, LNG trucks should not pass through the middle of the plant or through heavily congested areas but should have a safe route in and out of the installation.
- Occupied buildings should be located outside the hazard zones. If this is not possible, then they should be designed to prevent gas ingress and withstand the foreseeable loads from fires and explosions.
- It is necessary to consider constructability and maintenance. During construction space is required for material layout areas, cranes etc.

Figure 1. Example of layout of LNG terminal. Reganosa LNG Terminal, Spain.

### 2.3 Process and Safety Control Systems

The objective of process control is to operate the plant safely and efficiently. Normal plant control and monitoring are carried out via the plant control and monitoring system (PCS). Control loops and trips are implemented to ensure that the plant is operating within the design operational envelope. If the PCS fails to control a hazardous or undesirable condition, a safety control system (SCS) will initiate emergency shut-down trips to return the plant to a safe state.

The Safety Control System (SCS) controls and monitors all emergency shutdown functions and safety instrumented systems. The SCS system should be independent of the PCS to provide an extra protection layer.

### 2.3.1 Isolation and Emergency Shutdown

If an incident leads to loss of containment, the released material can form a flammable or toxic vapour cloud and/or fuel a fire. Therefore, the most effective way of mitigating the consequences of an incident after a leak has occurred is to limit as much as possible the amount of material released.

To achieve this, the process plant is sectioned by emergency shutdown (ESD) valves. These valves serve to isolate the section of the plant where the incident occurred, in order to reduce the amount of material released whilst avoiding an unnecessary and costly shutdown of the entire facility. Each process area will have its own discrete ESD level. When a loss of containment is detected (either by fire, gas or spill detectors or visually by an operator) the operator will receive an alarm in the control room. The operator should then start ESD by local or control room pushbuttons.

Safety instrumented systems are designed to isolate and/or shut down relevant equipment and process systems in a safe and predetermined manner via the SCS.

A good plant design should not have an excessive number of alarms to avoid alarm flooding; for example, EEMUA 191 recommendations should be followed to prevent the operators from experiencing alarm fatigue and then failing to act when a genuine emergency occurs.

## 3 Detailed Terminal Design

### 3.1 Marine Installations

Marine installations have specific hazards due to the presence of one or more ships carrying large amounts of flammable liquefied gases. Since the vessel floats, it has the potential to drift. Most terminals are located within busy industrial ports, thus there is a risk of collision between vessels carrying hazardous cargoes. In some cases, jetties are shared with other terminal operators handling very different materials, which pose risks not normally considered for liquefied gases (e.g. very toxic materials). Furthermore, the very nature of the industry means that ships using the terminals have crews from all over the world. This requires special attention to human factors when designing the jetty operations, to minimise the potential for human errors due to linguistic or cultural differences.

The main hazard associated with ship loading and unloading is the potential for a large release of liquefied gases, which will rapidly evaporate on contact with water, creating a large flammable cloud. This cloud can ignite resulting in a flash fire and, if enough liquid accumulates, a pool fire. Furthermore, for LNG releases under certain conditions, a Rapid Phase Transition (RPT) resulting in damaging overpressures can occur (Melhem, 2006). To ensure safe and efficient product transfer, hydraulically operated marine transfer arms installed on the jetty are fitted with quick connect/disconnect (QCDC) and Powered Emergency Release Couplings (PERC). The coupler system automatically detects a potentially hazardous situation caused by a ship drifting beyond the safe envelope of the transfer arm in time to initiate a safe emergency release of the vessel without loss of containment or equipment damage.

A ship-to-shore link facilitates bi-directional communications (both operation and emergency signals) between ship and terminal to enable safe operation and automatic shutdown if required. The jetty is normally equipped with an impounding basin to collect released liquids, in order to mitigate against the risk of large pool fires and RPT.

Figure 2. Marine transfer arms at Reganosa LNG Terminal, Spain.

## 3.2 Transfer System

The transfer system consists of the piping between the jetty and the terminal as well as the associated valves and instrumentation. The transfer piping system is maintained liquid full at cryogenic conditions allowing quick start-up whilst avoiding the formation of vapour pockets, which could lead to slug formation and development of unsafe loads (i.e. any load greater than the design loads) during start-up due to hammer effects. In case of long periods between transfer operations, a flexible process design can be developed to allow complete draining, followed by controlled safe re-cooling of the piping system. In emergency situations the emergency shutdown (ESD) system enables all product transfer activities to be stopped and the critical process units to be isolated in a safe and reliable manner.

The risk of hydraulic pressure surge occurs during transient conditions when transferring cryogenic fluids in long piping systems, for example due to the rapid operation of valves in case of an emergency shutdown. To ensure that dynamically generated peak pressure and piping loads are maintained below the piping and support design parameters, hydraulic transient surge analysis is performed for multiple operating and emergency scenarios. This helps ensure an inherently safe piping and structural design.

When ESD valves are closed, cryogenic liquids can become trapped and unable to expand. In order to avoid overpressure caused by the warming of such trapped liquids, thermal safety valves (TSV) are installed on piping systems. These protect the system against over-pressure as the fluid volume expands due to an increase in temperature caused by heat ingress to the piping. In order to avoid unnecessary flaring or releases to atmosphere, the thermal safety valves (TSV) will vent the generated vapour back to the tank; because of its large volume, it can absorb the extra volume without risk of over pressurising.

Figure 3. Transfer system- Vysotsk LNG Terminal, Russia.

## 3.3 Storage Tank

The design, construction and testing of the storage tank is of paramount importance to the safety of the terminal and its surroundings, given that it contains the largest inventory of flammable materials. The ultimate objective is to maintain the tank integrity at all times. For example, the tank should be able to withstand all operational loads and should not suffer from progressive collapse under accidental loading. It should also maintain its integrity when exposed to certain natural forces such as an earthquake. In Europe, the design and construction of vertical cryogenic storage tanks should follow standard EN 14620.

A concrete-steel full containment tank (CS-FCT) is inherently safer than other tank designs. The standard design includes submerged in-tank pumps for liquid send-out via the top of the tank, avoiding the risk of uncontrolled releases associated with bottom outlets. Concrete-steel full containment tanks do not require bunding, which can significantly reduce the space required for their construction. CS-FCT also provide increased flexibility in the overall plant layout, leading to potentially significant savings in the amount of land required, since their outer concrete shell provides enhanced protection from fire and explosion overpressure, as well as flying missiles in case of accidents in adjacent parts of the plant. Additionally, the failure risk of a CS-FCT is about 200 times lower than a single containment tank, decreasing the overall risk of the facility.

In addition to mechanical and structural design assurance, the tank design includes multiple layers of protection for both level and pressure in order to prevent:

- Tank over-filling: Independent level measurements (e.g. radar and servo level measurement instruments), multi-level alarming, interlocks for equipment shutdown and finally activation of Unloading Emergency Shutdown.

- Overpressure: The overpressure protection covers various upset scenarios e.g. atmospheric pressure drop, tank rollover, gas injection control valve failure, displacement due to filling, external fire etc.

Overpressure protection is achieved primarily via stepwise operation of the Boil-Off-Gas (BOG) compressors, followed by an interlock which isolates the tank and a pressure control valve releasing excess gas to the flare. A discretionary vent valve that the operator may open from the control room is often installed on top of the tank to avoid lifting the tank relief valves if tank pressure increases further. The ultimate layer of protection against overpressure will be achieved by a set of Pressure Safety Valves (PSVs), mounted on the tank roof to relieve excess pressure to the atmosphere.

Another important consideration during tank design is rollover. The term rollover refers to the rapid release of LNG vapours from a storage tank caused by liquid stratification, which can occur when two separate layers of different densities (due to different LNG compositions) exist in a tank (GIIGL, 2012-2015). According to international codes for LNG installations (EN 1473 and NFPA 59A), the tank Pressure Safety Valves (PSVs) have to be sized to handle the rollover scenario. Although the PSVs will prevent over-pressurisation and failure of the tank, their activation can still create a hazard due to the large amount of natural gas that could be released to atmosphere. Furthermore, given that methane is a powerful greenhouse gas, venting through the PSVs should be avoided whenever possible. There are several measures to prevent stratification and thus reduce the potential for rollover.

- Prevention: Selection of top and bottom filling mode depending on the LNG composition. Denser liquid is loaded above the LNG already in the tank and lighter liquid is loaded into the bottom of the tank. This will lead to natural mixing and a more homogeneous composition. Regular additional mixing of tank contents by circulation of LNG using the in-tank pumps in kickback mode also prevents stratification.
- Mitigation: The tank is equipped with LTD (level, temperature and density) type of level gauging to detect stratification and initiate corrective measures. If stratification is detected, LNG can be re-circulated to prevent rollover. This mixing aims to achieve a more homogeneous composition and to release any trapped heat or vapour within the product being moved.

Vacuum conditions in the tank also need to be prevented. Under normal operations, the control of vacuum conditions is achieved by: (1) shutdown of BOG compressors; (2) shutdown of send-out pumps. Under abnormal conditions and after shutdown of BOG compressors and in-tank pumps, vacuum is prevented by the injection of gaseous nitrogen and/or high-pressure gas into the tank. However, the ultimate protection of the tank against vacuum is achieved by a set of air vacuum breakers, mounted on the tank roof to admit air into the tank.

### 3.4 Boil-Off Gas (BOG) and displaced vapours handling

BOG is generated inside the tank by ambient heat ingress into the tank, by flashing and by displacement during tank filling. Normally the pressure of the tank vapour space and terminal vapour system is controlled by operation of the BOG compressors to direct excess vapours to send-out stream(s). During ship unloading, a part of BOG is routed via the boil-off gas header to the ship’s cargo tank to prevent under-pressure in the carrier tank. The remaining BOG is sent to the BOG compressors. In case the BOG compressors are overloaded or unavailable, excess BOG will be vented to the flare system by the tank pressure control system. During normal operation, no flaring is expected.

### 3.5 Truck Loading

In most terminals, LNG is transported to end users by road. Trucks specially designed to carry LNG are loaded from the storage tank using either hard arms or cryogenic hoses. To ensure safety during truck loading, product transfer follows a strict protocol encompassing a badge control system, truck weighing and mass flow monitoring.

Cryogenic transfer arms are equipped with couplings that allow for quick connection between process systems and truck. Break-away couplings can be used in the design of transfer lines to reduce the amount spilled in case of truck pull-away.

Multiple safety systems ensure safe truck loading. To reduce the probability of human error, a process control system automatically transfers pre-programmed batches of product between terminal and truck on the basis of available truck ullage. Upon detection of abnormal process parameters or activation of the fire and gas detection system, a separate emergency shutdown (ESD) system blocks the truck loading facilities to ensure the safe and reliable stop of all transfer activities.

### 3.6 Vaporisation and Vapour Send-Out

If gaseous sendout to a pipeline network is required, the terminal will also include facilities for vaporisation and gas metering. If the pipeline operates at high pressure, high pressure cryogenic pumps are required to increase the liquid pressure before vaporisation.

The main hazard associated with this operation is the potential for high pressure releases (30-60 barg), either liquid releases between the pumps and the vaporiser inlet or gas releases downstream of the vaporiser. This can lead to large gas dispersion distances and potentially jet fires. It is important to minimise the releasable inventories by appropriate placement of isolation valves. High pressure terminal piping systems are typically designed such that the pressure delivered by the pump cannot exceed the design pressure of the pipeline. However, external mains pipelines are often of lower design pressure in which case a High Integrity Pressure Protection System (HIPPS) might be required to prevent over-pressurisation of the mains pipeline.

Depending on their type, vaporisers can create large congested areas (e.g. ambient air vaporisers that rely on a large surface area for heat transfer). In case of loss of containment and ignition, this area can be a source of relatively high explosion overpressures. It is important to consider these aspects during layout development and if possible, separate the vaporisers into smaller units to limit the maximum explosion overpressure that could be generated (c.f. layout section 2.2).

### 3.7 Flare

Terminals are designed for zero flaring during normal operation with complete boil-off gas (BOG) recovery to send-out systems via recondensation, compression, liquefaction, etc. The plant flare is intended to be used only during commissioning and maintenance (e.g. BOG compressor out of operation) or in an emergency scenario.

The most likely emergency scenarios involve overpressure in the storage tank. Most overpressure scenarios can be handled by the tank pressure control system, which routes excess gases to the flare. In order to avoid unnecessary flaring, PSV discharges from low pressure systems, including the BOG recovery system and liquid collection pipes, are routed to the tank BOG header to recover the discharged gas back to the storage tank. Likewise, relief from thermal expansion valves within the process area will be collected and both vapour and liquid phases are sent back to the storage tank. This minimises liquid and gaseous discharges from the plant during normal operation.

The location of the flare requires consideration of the predominant wind direction and the proximity of processing units and occupied buildings. Typically, an elevated flare with a sterile area at ground level is specified that, depending on the product and environmental legislations, can be air assisted to ensure complete combustion and adherence to regulations. However, often there is not sufficient space for a sterile area, in which case two options are available:

- Increased flare height to reduce radiation at ground level. This is costly, as it might require a larger structure.
- Enclosed ground flare. If space is constrained, or low visibility is of environmental priority, this type of flare provides a more compact design which reduces visual impact by combusting the product with a fully

enclosed flame whilst providing low NOx staged combustion across the full range of relief scenarios. This option is also expensive but may be the only possibility in constrained plots.

Figure 4. Enclosed ground flare- Shenzhen LNG Terminal, China.

## 4. Fire and Cold Embrittlement Protection

Although all foreseeable precautions are taken during plant design, it is still possible for a loss of containment to occur. Experience also shows that it is impossible to exclude all ignition sources, meaning that a fire remains a credible scenario. A Fire Hazard Assessment (FHA) is undertaken during the detailed design phase to identify equipment and structures to be protected in case of fire to minimise the risk of escalation. The FHA informs the design of mitigation measures, including:

- Fire, gas and spill detection to warn personnel of accidental product release and in some case, to automatically activate the Emergency Shutdown System (ESD)
- Active fire systems to cool down equipment and structures subjected to high thermal loads.
- The tank PSVs are often equipped with dry powder extinguishing systems, activated automatically by fire and/or heat detectors.
- Impounding basins to collect any cryogenic spills. The extent of potential liquid pools is restricted by containing spills within defined impounding and spill collection areas. This reduces the area for evaporation, in turn decreasing the extent of the flammable cloud dispersion and the potential radiation in case of a pool fire. It also prevents major leaks spreading to adjacent process areas and/or the environment, thus decreasing the potential for escalation.
- Foam systems and/or foam glass blocks to reduce the dispersion of flammable gases and fire radiation from impounding basins.
- Passive fire protection (fireproofing) of equipment, piping and structures whose failure could lead to rapid escalation.

A detailed FHA can also be used to check the availability of emergency evacuation routes in case of fire to ensure they do not become impaired by thermal radiation.

Equipment and structures that are not designed for cryogenic temperatures can also be endangered by contact with cryogenic fluids in case of a loss of containment. Therefore, it is important to analyse the impact of very low temperature spills on the surroundings of the leak source. When necessary, equipment and structures should be protected by appropriate insulating materials. Cryogenic embrittlement protection of load-carrying steel structures can be provided by placing them on concrete pedestals, to avoid prolonged contact with cryogenic fluids.

## 5. Conclusion

Throughout this paper we have described how a multidisciplinary approach between process safety, process design, plant design, structural and instrumentation engineers can achieve a terminal design that offers maximum reliability, operability and safety.

## References

Alderman, P.E.; Pitbaldo, R.; Thomas, J.K.; 2014; Facilitating Consistent Siting Hazard Distance Predictions Using the TNO Multi-Energy Model, Journal of Loss Prevention in the Process Industry. 30, 287-295.

API Standard 521; Pressure-relieving and Depressuring Systems, 6th Edition, 2014.

Centre for Chemical Process Safety (CCPS), 2010, Guidelines for Vapour Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards.2nd Edition.

EEMUA 191, Third Edition – Alarm Systems, A guide to design, management and procurement.

EN 14620-1: 2006-12; 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 1473:2016; Installation and equipment for liquefied natural gas –Design of onshore installations.

GIIGNL International Group of Liquefied Gas Importers, Rollover in LNG storage tanks, 2nd Edition:2012-2015. Public Version.

International Gas Union, 2019 World LNG Report.

LNG Fire Protection & Emergency Response, BP Process Safety Series, IChemE, 2009.

Melhem, Georges & Ozog, Henry. 2006; Understand LNG Rapid Phase Transitions (RPT). Hydrocarbon Processing. 85.

NFPA 59A, Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG), 2019.