LNG INFORMATION PAPER

#7

2021 Update

FSRU (Floating Storage Regasification Unit)

CONTENTS

GIIGNL's Technical Study Group introduces a series of Information Papers that provide factual information about Liquefied Natural Gas (LNG). This paper describes the design and operation of floating terminals, an increasingly important means of storing and regasifying LNG. It also explains the measures the industry implements as standard practices to detect, control and minimize potential effects from a release of LNG.

INTRODUCTION

Projects in service, cost and schedule considerations

According to the GIIGNL Annual Report 2021, there are now 43 LNG import markets worldwide which offer a combined 947 million tonnes per annum (mtpa) of LNG regasification capacity. As the number of regasification terminals grows, an increasing number of projects are utilizing floating LNG storage and/or regasification facilities. A floating terminal may be an attractive option where it is difficult to secure a suitable onshore site or where limited time is available (construction of the storage tanks for an onshore terminal can take up to 4 years, whereas the time to develop a floating terminal can be much shorter, particularly when leasing an existing vessel). Floating terminals also have a relatively low initial capital cost and can potentially be relocated if circumstances change. There are currently 32 floating terminals in operation around the world.

TYPE OF VESSELS

FSRUs, FSUs and FRUs

The configuration of a floating terminal can vary depending on the location, the choice of technology and safety and environmental considerations. The most common configurations include:

Figure 1. FSRU *(Source: MOL)*

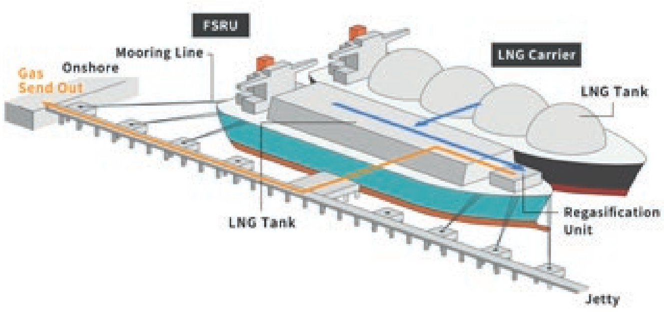


Figure 2. Example of FSRU process *(Source: MOL)*

- Floating Storage and Regasification Units (FSRUs) with LNG storage tanks and regasification facilities located on a single vessel.
- Floating Storage Units (FSUs) connected to separate regasification facilities that may themselves be located on a separate Floating Regasification Unit (FRU), a jetty or onshore.
- Modified LNG Carriers (LNGCs), sometimes known as Shuttle Regasification Vessels (SRVs), capable of discharging regasified LNG into a subsea pipeline via an unloading buoy.

Newbuild vs. conversion

The majority of floating terminals utilizes vessels that are based on standard LNG Carrier designs. Vessels can either be newbuilds or conversions of existing ships, with the decision about which approach to adopt depending on factors including project timeline, capacity requirements, geography and cost. While projects vary considerably, converting an existing vessel can take as little as 18 to 24 months whereas delivering a newbuild facility can take up to three years. Using a newbuild vessel gives the flexibility to tailor specifications to the requirements of a specific project. Redeployment of an existing Floating Terminal to a new location can be an attractive option when regasification capacity is required quickly.

TECHNOLOGY

Mooring Systems

Floating terminals can be moored against conventional jetties or in open water utilizing a turret, a buoy or spread-mooring. Mooring systems are designed to withstand the forces of waves, wind, and currents and can be designed to hold vessels in place even during bad weather. Each project will select the most suitable mooring system for its location (nearshore or offshore) and environmental conditions. Vessels can be moored in water depths from around 10 meters upwards.

LNG/Gas Transfer Systems (MLAs, Hoses)

The two transfer systems used by floating terminals are cryogenic flexible hoses and hard-piped, articulated Marine Loading Arms (MLAs). Both are specifically designed to transfer cargo safely from the manifold of a visiting LNGC to the floating terminal. Most transfer systems are fitted with an emergency disconnection system (known as a Powered Emergency Release Coupling or PERC) that allows the rapid disconnection of the LNGC from the terminal in the event of excessive movement of the LNGC. The design of the PERC protects the LNGC's manifold connection and the floating terminal's hard arms/hoses from damage as well as limiting the amount of LNG or gas that could potentially be released. The choice of whether to use flexible hoses or MLAs will be determined by operator preference, site environmental conditions and local regulations. In both cases, the results of detailed hydrodynamic studies are used to develop a safe operating envelope for the transfer system.

Figure 3. Flexible Hoses *(Source: JAPEX)*

Figure 4. Marine Loading Arms *(Source: Jawa Satu Regas)*

LNG Storage

Most floating terminals are based on standard LNGC designs. These double-hulled vessels blend conventional ship design with specialized materials to contain the cargo at close to atmospheric pressure and a temperature of

approximately -162 °C (-259 °F). 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 as per the IGC (IMO International Gas Code) and add layers of protection in the event of grounding or collision. LNG Ships are described in more detail in **Information Paper No.3**.
Some smaller FSRUs utilise Type-C pressurised tanks.

Regasification Systems

LNG from the storage tanks is pumped up to the required export pressure (typically 50 to 120 bar) and sent to vaporisers that heat and regasify itself. Energy for regasification is typically provided by extracting heat from seawater and/or combustion of a small fraction of the natural gas sendout. Regasification systems generally fall into one of three different categories. These systems could either be an integral part of the FSRU or located externally, for instance on an FRU:

1. Open loop regasification systems

In an open loop system, seawater is drawn into the FSRU and passed through heat exchangers to vaporize the LNG. The vaporization process causes a drop in seawater temperature, which is then discharged externally on a continuous basis.

2. Closed loop regasification systems

In a closed loop system, an intermediate fluid (for example seawater, freshwater/glycol or propane) is heated by the combustion of natural gas before being passed through the LNG vaporizers. The intermediate fluid is then recirculated back to the heaters. Because the system does not require a continuous supply of seawater, it is useful in locations where regulations prohibit the discharge of cold water or where water containing high sediment levels could damage regasification system components.

3. Hybrid regasification systems

In a hybrid system, the basic design is an open loop system as described above. However, the FSRU is also able to heat the incoming seawater using natural gas heaters. This system is useful where an FSRU is operating in a location with seawater temperatures that would not allow efficient LNG vaporization (typically below 15°C).
FSRUs may be built to operate with a single system only or with the ability to switch between systems. The latter is more useful if there is high seasonality between seawater conditions, or if the FSRU is expected to operate in multiple locations over its lifetime.

The choice of regasification system will be determined by a combination of operator preference, local regulations and governmental considerations such as effluents from open loop systems and atmospheric emissions from closed loop systems.

BOG Management

Boil off gas (BOG) produced during storage or process operations may be handled using equipment traditionally found on LNGCs, such as power generation, steam dumping or Gas Combustion Units (GCUs). In addition, FSRUs can be fitted with equipment that offers further BOG management options including :

1. Recondenser

BOG can be recondensed back into LNG using a packed column – known as a recondenser - located between the FSRU's cargo pumps and the high-pressure send-out pumps. In the recondenser, BOG is mixed with sub-cooled LNG pumped from the cargo tanks and, because the LNG is below its boiling point, it condenses the BOG back into LNG. Recondensed BOG is mixed with the main LNG flow, pumped up to sendout pressure, vaporised and exported.

2. Gas sendout compressors

A gas sendout compressor allows BOG to be routed directly into the gas export system by increasing its pressure to the sendout pressure.

3. Reinforced tanks

Using specially designed LNG storage tanks that can operate at a higher pressure reduces the volume of BOG generated allowing for greater flexibility during cargo transfers and periods of low sendout.

4. Reliquefaction

BOG can be cooled and condensed back into LNG in a cryogenic heat exchanger using a refrigerant such as nitrogen. LNG produced in the reliquefaction unit is returned to the cargo tanks.

ENVIRONMENTAL CONSIDERATIONS

Metocean (weather/reliability)

It is essential for an FSRU project to select a site based on meteorological and oceanographic studies and to ensure that the terminal is designed to operate safely at the chosen site. Analyzing historical data about the weather and marine conditions (such as wind speed, wind direction, wave height, tides etc.) allows a project to understand the extreme conditions at the proposed site as well as the frequencies with which various weather and marine conditions occur. This in turn reduces uncertainty in the terminal's specifications and enhances safety, operational efficiency and reliability.

Environmental and Social Impact Assessment

FSRU projects will normally carry out an Environmental and Social Impact Assessment (ESIA) during the early stages of the project's development. Although the exact scope of the ESIA will vary between countries, it will generally require a project to identify, quantify and mitigate any relevant environmental and social consequences of the proposed development (e.g. air quality, habitat quality, water use and discharge, noise levels, marine mammal activities).

SAFETY AND SECURITY (SAFETY STUDIES, CONTINGENCY PLANNING)

Since FSRUs are equipped with more complex process equipment than conventional LNGCs, there is a requirement for developers to follow a rigorous approach to managing process safety risks that includes carrying out a comprehensive set of safety studies, including a Hazard Identification (HAZID) study, a Hazard and Operability (HAZOP) study and a Quantitative Risk Assessment (QRA). Terminals will also have security plans that must comply with ISPS Code regulations as well as specific host country or local authority's requirements.

For additional information on the contingency planning (emergency response plan), please refer to **Information Paper No.6**.

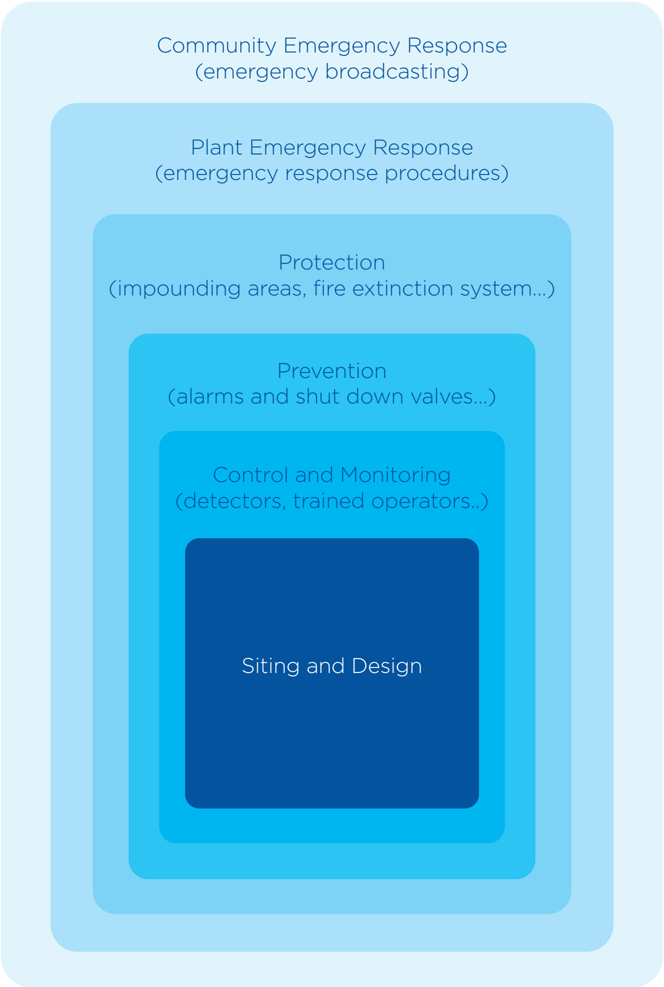


Figure 1. of Information Paper No.6
Layers of protective measures to prevent escalation of an LNG leak into a pool fire *(Source: BV 2009)*

REGULATION, CODES AND STANDARDS (NATIONAL AND INTERNATIONAL STANDARDS, CLASSIFICATION)

The environmental and safety features of floating terminals have been extensively studied by energy companies, shipyards, ship classification societies, owners, engineering companies and equipment vendors. The facilities are generally designed and constructed to meet the requirements of national and international standards, ship classification societies and flag state administrations as well as LNGCs. This ensures a predictable and structured set of requirements that are familiar to designers, shipyards and regulators as well as investors, lenders and insurers. For additional information on the regulations, codes and standards which apply to FSRUs as well as LNGCs, please refer to **Information Papers No.4 & 5**.

KEY POINTS AND CONCLUSIONS

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

1. As the increasingly diverse LNG trade prompts expanded needs in regasification terminals, numerous projects using Floating Storage and Regasification units (FSRUs) are currently underway and some are already in operation.

2. There are several variations on conventional FSRU projects, including FSUs and FRUs. The optimum configuration will vary depending on specific project requirements, including location, performance requirements and local regulations.

3. A floating terminal may be an attractive option where it is difficult to secure a site or construction permits for an onshore terminal or where limited time is available. Floating terminals also have a relatively low initial capital cost and can potentially be relocated if circumstances change. However, LNG storage volumes are limited (typically less than 180,000 m^3 and maximum 240,000m^3, which limits the flexibility to expand).

4. All the necessary components of the FSRU will have to be compliant with IMO, flag state, ship classification society and all applicable and relevant national and local maritime and environmental authorities. Many safety, environmental and risk studies must be conducted from the early stage of the FSRU project development.

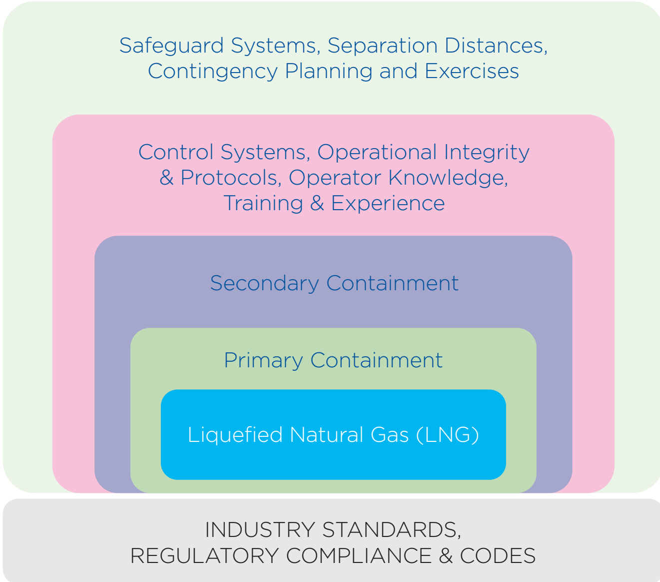
5. Typical layers of protection implemented in FSRUs as well as onshore LNG terminals are graphically illustrated in **Figure 1** of **Information Paper No.6**. These layers begin, in a sense, with the Siting and Design of the terminal. The next layer reflects the Control and Monitoring features (including, 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 fighting 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, mobilizes additional response resources to reinforce the facility's response, and thereby protects the public and adjacent properties.

6. Energy companies, owners, shipyards, classification societies, engineering contractors and equipment vendors have worked together to develop floating terminals that can achieve a level of safety and environmental performance comparable to that of onshore terminals.

7. As reflected in the illustration below, 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.

MULTIPLE SAFETY LAYERS MANAGE LNG RISK



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