ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINES FOR LIQUEFIED NATURAL GAS FACILITIES

INTRODUCTION

1. The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice.[1] When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS Guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry sector guidelines may be necessary. A complete list of industry sector guidelines can be found at www.ifc.org/ehsguidelines.

2. The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

3. The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

4. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

APPLICABILITY

5. The EHS Guidelines for Liquefied Natural Gas (LNG) Facilities include information relevant to LNG base load liquefaction plants, transport (by sea and land), storage, regasification (including floating storage regasification units), peak shaving terminals, and LNG fueling facilities. For coastal LNG facilities—including harbors, jetties, and in general coastal facilities (e.g., coastal terminals, marine supply bases,

[1] Defined as the exercise of professional skill, diligence, prudence, and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity, as well as varying levels of financial and technical feasibility.

loading/offloading terminals), additional guidance is provided in the **EHS Guidelines for Ports, Harbors, and Terminals**. For EHS issues related to vessels and floating storage units, additional guidance is provided in the **EHS Guidelines for Shipping**. EHS issues associated with road transportation of LNG are addressed in the **General EHS Guidelines**. Issues related to liquefied petroleum gas/condensate production and storage in liquefaction plants are not covered in this Guideline.

This document is organized in the following manner:

1. INDUSTRY-SPECIFIC IMPACTS AND MANAGEMENT

6. This section provides a summary of EHS issues associated with LNG[2] facilities, along with recommendations for their management. These issues may be relevant to any of the activities listed as applicable to these Guidelines. Additional guidance for the management of EHS issues common to largest industrial facilities during the construction and decommissioning phases is provided in the **General EHS Guidelines**.

1.1 Environment

7. The following environmental issues should be considered as part of a comprehensive assessment and management program that addresses project-specific risks and potential impacts. Potential environmental issues associated with LNG facilities include the following:

- Hazardous material management
- Wastewater discharges
- Air emissions
- Waste management
- Noise generation
- LNG transport related issues
- LNG fueling related issues

[2] Natural gas consists primarily of methane, but commonly includes varying amounts of other higher alkanes, and sometimes a small percentage of carbon dioxide, nitrogen, hydrogen sulfide, or helium.

1.1.1 Hazardous Materials Management

8. Storage, transfer, and transport of LNG may result in leaks or accidental release from tanks, pipes, hoses, and pumps at land installations and in LNG transport vessels and vehicles. The storage and transfer of LNG also poses a risk of fire and, if under pressure, explosion, due to the flammable characteristics of its boil-off gas (BOG).

9. In addition to the recommendations for hazardous materials and oil management discussed in the **General EHS Guidelines**, recommended measures to manage these types of hazards include the following:

- LNG storage tanks and components (e.g., pipes, valves, and pumps) should meet internationally recognized standards for structural design integrity and operational performance to avoid catastrophic failures and to prevent fires and explosions during normal operations and during exposure to natural hazards. Applicable internationally recognized standards may include provisions for commissioning, overfill protection, secondary containment, metering and flow control, fire protection (including flame-arresting devices), and grounding (to prevent electrostatic charge).[3]
- Storage tanks and components (e.g., roofs and seals) should undergo periodic inspection for corrosion and structural integrity and be subject to regular maintenance and replacement of equipment (e.g., pipes, seals, connectors, and valves).[4] A cathodic protection system should be installed to prevent or minimize corrosion, as necessary.
- Loading/unloading activities (e.g., transfer of cargo between LNG carriers and terminals) should be conducted by properly trained personnel according to pre-established formal procedures to prevent accidental releases and fire/explosion hazards. Procedures should include all aspects of the delivery or loading operation from arrival to departure, connection of grounding systems, verification of proper hose connection and disconnection, and adherence to no-smoking and no-naked-light policies for personnel and visitors.[5]

Spills

10. LNG is a cryogenic liquid (its boiling point at atmospheric pressure is −162°C (−259°F)) that is not flammable in liquid form. However, BOG (that is mainly methane) forms as the LNG warms, and under

[3] See U.S. Code of Federal Regulations (CFR) Title 49, Part 193: Liquefied Natural Gas Facilities: Federal Safety Standards (2006) and European Standard (EN) 1473: Installation and Equipment for Liquefied Natural Gas—Design of Onshore Installations (2016), National Fire Protection Association (NFPA) 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2016), NFPA 52 Vehicular Gaseous Fuel Systems Code (2013) and EN 13645: Installations and Equipment for Liquefied Natural Gas—Design of Onshore Installations with a Storage Capacity Between 5 metric tons and 200 metric tons (2002), and relevant ISO Standards.

[4] Several methods exist for inspecting tanks. Visual inspection may reveal cracks and leaks in tanks. X-ray or ultrasonic analysis can be used to measure wall thickness and pinpoint crack locations. Hydrostatic testing may indicate leaks caused by pressure, while a combination of magnetic flux eddy current and ultrasonic analysis can be used to detect pitting.

[5] Examples of good practice for LNG loading and unloading include Liquefied Gas Handling Principles on Ships and in Terminals—3rd edition (1999), Society of International Gas Tanker and Terminal Operators Ltd (SIGTTO), and U.S. CFR Title 33, Part 127: Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas.

certain conditions could result in a vapor cloud if released. Uncontrolled releases of LNG could lead to jet or pool fires if an ignition source is present, or to a methane vapor cloud that is potentially flammable (flash fire) under unconfined or confined conditions if an ignition source is present. LNG spilled directly onto a warm surface (such as water[6]) could result in a sudden phase change known as a Rapid Phase Transition (RPT).[7]

11. In addition to recommendations for emergency preparedness and response provided in the **General EHS Guidelines,** recommended measures to prevent and respond to LNG spills include the following:

- Conduct a spill risk assessment for the facilities and related transport/shipping activities, supported by internationally recognized models.
- Develop a spill prevention and control plan that addresses significant scenarios and magnitude of releases. The plan should be supported by the necessary resources and training. Equipment to respond to small spills that are operational in nature must be available at the facility. Arrangements and procedures to mobilize external resources in responding to larger spills and strategies for their deployment should be included, together with a full list describing the nature, location, and use of on-site and off-site response equipment and the response times for its deployment.
- Develop spill control response plans in coordination with the relevant local regulatory agencies.
- Equip facilities with a system for the early detection of gas releases, designed to identify the existence of a gas release and to help pinpoint its source so that operator-initiated Emergency Shutdown (ESD) systems can be rapidly activated, thereby minimizing the inventory of gas releases.
- Make an ESD system available to initiate automatic transfer shutdown actions in case of a significant LNG leak.
- For unloading/loading activities involving LNG carriers and terminals, prepare and implement spill prevention procedures for carrier loading and off-loading according to applicable internationally recognized standards and guidelines which specifically address advance communications and planning with the receiving terminal.[8]
- Ensure that onshore LNG storage tanks are designed with adequate secondary containment (e.g., high nickel-content welded steel inner tank and reinforced concrete outer tank; single wall tank with an external containment basin, full containment tank design) so as to contain a sudden release.

[6] LNG vaporizes rapidly when exposed to ambient heat sources such as water, producing approximately 600 standard cubic meters of natural gas for each cubic meter of liquid.

[7] A potentially significant environmental and safety hazard from LNG shipping is related to RPT that can occur when LNG is accidentally spilled onto water at a very fast rate. The heat transfer from water to spilled LNG causes LNG to instantly convert from its liquid phase to its gaseous phase. The large amount of energy released during a RPT can cause a physical explosion with no combustion or chemical reaction. The hazard potential of rapid phase transitions can be severe, but is generally localized within the spill area.

[8] See U.S. CFR Title 49, Part 193: Liquefied Natural Gas Facilities: Federal Safety Standards (2006), EN 1473: Installation and Equipment for Liquefied Natural Gas—Design of Onshore Installations (2016), and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2016).

- Facilities should provide grading, drainage, or impoundment for vaporization, process, or transfer areas able to contain the largest total quantity of LNG or other flammable liquid that could be released from a single transfer line in 10 minutes.[9]
- Ensure that material selection for piping and equipment that can be exposed to cryogenic temperatures follows international design standards.[10]
- In case of a gas release, allow safe dispersion of the released gas, maximizing ventilation of areas and minimizing the possibility that gas can accumulate in closed or partially closed spaces. Spilled LNG should be left to evaporate and evaporation rate should be reduced, if possible, (e.g., by covering with expanding foam).
- Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the fire and explosion risk and environmental discharge. The LNG spill drainage system (trough and sump system) design should be optimized to reduce vaporization rates to limit the overall vapor dispersion area.[11]

1.1.2 Wastewater Discharges

12. The **General EHS Guidelines** provide information on wastewater management, water conservation and reuse, along with wastewater and water quality monitoring programs. The guidance below is related to additional wastewater streams specific to LNG facilities.

Cooling Water and Cold Water Streams

13. The use of water for process cooling at LNG liquefaction facilities and for re-vaporization heating at LNG receiving terminals may result in significant water use and discharge streams. Recommendations to control once-through thermal process water use and discharge streams include the following:

- Water conservation opportunities should be considered for LNG facility cooling systems (e.g., air-cooled heat exchangers in place of water-cooled heat exchangers, and if applicable, opportunities for the integration of cold water discharges with other proximate industrial or power plant facilities). The selection of the preferred system should balance environmental benefits and safety implications of the proposed choice.[12] Additional guidance on water conservation is provided in the **General EHS Guidelines**.
- Cooling or cold water should be discharged to surface waters in a location that will allow maximum mixing of the thermal plume to ensure that the temperature is within 3 degrees Celsius of ambient temperature at the edge of the mixing zone, according to guidance provided in the **General EHS Guideline** and as noted in Table 1 of Section 2.1 of this Guideline.

[9] EN 1473 standard suggests that the impoundment system be considered on the basis of a Risk Assessment.

[10] NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2016) and NFPA 52 Vehicular Gaseous Fuel Systems Code (2013).

[11] For example, by directing LNG spill to a remote impoundment.

[12] For example, where space is limited (e.g., offshore), explosion risks are key in the decision of the preferred options. A balance in terms of an overall HSE risk ALARP approach is recommended.

- If biocides/chemical use is necessary, carefully select chemical additives in terms of dose concentration, toxicity, biodegradability, bioavailability, and bioaccumulation potential. Consideration should be given to residual effects at discharge using techniques such as risk-based assessment.

Other Wastewater Streams

14. Other wastewater discharges generated at LNG facilities include: drainage and storm water (from process and non-process areas), sewage wastewater, tank-bottom water (e.g., from condensation in LNG storage tanks), fire water system releases, wash down (equipment and vehicle) water, general oily waters, and other waters (e.g., hydrostatic test water). Pollution prevention and treatment measures that should be considered for these wastewaters include:

- *Sewage:* Gray and black water from showers, toilets, and kitchen facilities should be treated as described in the **General EHS Guidelines**.
- *Drainage and storm waters:* Separate drainage systems for drainage water from process areas that could be contaminated with hydrocarbons (closed drains) and drainage water from non-process areas (open drains) should be available to the extent practical and compatible with the LNG spills control systems listed in the Hazardous Materials Management section. All process areas should be bunded and have adequate site drainage via a closed sewer system to ensure that uncontrolled potentially hydrocarbon-contaminated surface run-off is avoided. Drainage tanks and slop tanks should be designed with sufficient capacity for foreseeable operating conditions, and systems to prevent overfilling should be installed. Drip trays, or other controls, should be used to collect run-off from equipment that is not contained within a bunded area and the contents routed to the closed drainage system. Storm water flow channels and collection ponds installed as part of the open drainage system should be fitted with oil/water separators. Separators may include baffle type or coalescing plate type and should be regularly maintained. Hydrocarbon-contaminated storm water runoff should be treated through an oil/water separation system able to achieve an oil and grease concentration below 10 mg/L, as noted in Section 2.1, Table 1 of this Guideline. Additional guidance on the management of storm water is provided in the **General EHS Guidelines**.
- *Firewater:* Firewater from regular test releases should be contained and directed to the facility's drainage system or to a storage pond and wastewater treatment system, if contaminated with hydrocarbons.
- *Wash waters:* Equipment and vehicle wash waters should be directed to the closed drainage system or to the facility's wastewater treatment system.
- *General oily water:* Oily water from drip trays and liquid slugs from process equipment and pipelines should be routed to the wastewater treatment system.
- *Hydrostatic testing water*: Hydrostatic testing of LNG equipment (e.g., storage tanks, facility piping systems, transmission pipeline connections, and other equipment) involves pressure testing with water during construction/commissioning to verify their integrity and to detect potential leaks. Chemical additives may be added to the water to prevent internal corrosion. Pneumatic testing with dry air or nitrogen may be employed for cryogenic piping and components. In managing hydrotest waters, the following pollution prevention and control measures should be considered:

- Reducing the need for chemicals by minimizing the time that test water remains in the equipment.
- Careful selection of chemical additives in terms of concentration, toxicity, biodegradability, bioavailability, and bioaccumulation potential.
- Using the same water for multiple tests.

15. If discharge of hydrotest waters to surface waters or land is the only feasible alternative for disposal, a hydrotest water disposal plan should be prepared that considers points of discharge, rate of discharge, chemical use (if any) and dispersion, environmental risk, and required monitoring. Hydrostatic test water quality should be monitored before use and discharge, and should be treated to meet the discharge limits in Table 1 in Section 2.1 of this Guideline.[13] Further recommendations for managing hydrotest water for pipelines are available in the two **EHS Guidelines for Onshore and Offshore Oil and Gas Development,** respectively.

1.1.3 Air Emissions

16. Air emissions sources (continuous or non-continuous) from LNG facilities include combustion for power and heat generation (e.g., boilers, or for dehydration and liquefaction activities at LNG liquefaction terminals, and regasification activities at LNG receiving terminals), and reciprocating and other engines (which may be used to drive large machinery such as compressors and pumps). Emissions resulting from flaring and venting, as well as from fugitive sources, may result from activities at both LNG liquefaction and regasification terminals. Principal air pollutants from these sources typically include nitrogen oxides (NO_X), carbon monoxide (CO), carbon dioxide (CO_2), and in case of sour gases, sulfur dioxide (SO_2).

17. For LNG plants with important combustion sources (including floating storage and regasification units moored long term), air quality impacts should be estimated by the use of baseline air quality assessments and atmospheric dispersion models to establish potential ground-level ambient air concentrations during facility design and operations planning, as described in the **General EHS Guidelines**. These studies should ensure that adverse impacts to human health and the environment are avoided or minimized.

18. Technically feasible and cost-effective attempts should be made to optimize energy efficiency and design facilities to reduce energy use with an overall objective of reducing air emissions. Additional recommendations on energy efficiency are addressed in the **General EHS Guidelines**.

19. Aggregate greenhouse gas emissions from all facilities should be quantified annually in accordance with internationally recognized methodologies.

Exhaust Gases

20. Exhaust gas emissions produced by the combustion of natural gas or liquid hydrocarbons in turbines, boilers, and engines for power and heat generation, can be the most significant source of air emissions

[13] Effluent discharge to surface waters should not result in significant impact on human health and sensitive habitats. A disposal plan that considers points of discharge, rate of discharge, chemical use and dispersion, and environmental risk may be necessary. Discharges points should be planned with consideration of environmentally sensitive areas, with specific attention to high water tables, vulnerable aquifers, and wetlands, as well as sensitive community receptors, including water wells, water intakes, and agricultural land.

from LNG facilities. Air emission specifications should be considered during all equipment selection and procurement.

21. Guidance for the management of combustion sources with a capacity of lower or equal to 50 megawatt thermals (MWth), including air emission standards for exhaust emissions, is provided in the **General EHS Guidelines**. For combustion source emissions with a capacity of greater than 50 MWth, refer to the **EHS Guidelines for Thermal Power.** Floating storage and regasification units permanently fixed to a berthing platform or moored long term in a port should meet air emissions standards applicable to stationary sources.

22. At regasification terminals, the selection of Submerged Combustion Vaporizers (SCV), Open Rack Vaporizers (ORV),[14] Shell and Tube Vaporizers, and Air Vaporizers should be assessed, taking into consideration baseline environmental conditions and environmental sensitivities. If other thermal energy is available within a short distance (e.g., a nearby refinery), waste heat recovery/shell and tube vaporizers could be considered.

Venting and Flaring

23. Flaring or venting is an important safety measure used at LNG facilities to ensure that gas is safely disposed of in the event of an emergency, power or equipment failure, or other plant upset condition. Flaring or venting should be used only in emergency or plant upset conditions. Continuous venting or flaring of boil-off gas under normal operations is not considered good industry practice and should be avoided. Guidance for good practice with respect to flaring and venting is provided in the **EHS Guidelines for Onshore Oil and Gas Development**.

Boil-Off Gas

24. After LNG liquefaction, stored LNG emits a small amount of methane gas vapor known as boil-off gas (BOG), due to heat gain from ambient conditions and tank pumps, in addition to barometric pressure changes. BOG should be collected using an appropriate vapor recovery system (e.g., compressor systems). For LNG plants (excluding LNG carrier loading operations) the vapor should be returned to the process for liquefaction or used on-site as a fuel; on board LNG carriers, BOG should be re-liquefied and returned to the storage tanks or used as a fuel; for re-gasification facilities (receiving terminals), the collected vapors should be returned to the process system to be used as a fuel on-site, compressed and placed into the sales stream/pipeline, or flared.

Fugitive Emissions

25. Fugitive emissions at LNG facilities may be associated with cold vents, leaking pipes and tubing, valves, connections, flanges, packings, open-ended lines, pump seals, compressor seals, pressure relief valves, and general loading and unloading operations. Methods for controlling and reducing fugitive emissions should be considered and implemented in the design, operation, and maintenance of facilities. The selection of appropriate valves, flanges, fittings, seals, and packings should consider safety and

[14] If ORVs are used for LNG vaporization, no air emissions are expected from an LNG regasification terminal during normal operations, except for fugitive emissions of methane-rich gas.

suitability requirements, as well as their capacity to reduce gas leaks and fugitive emissions.[15] Additionally, leak detection and repair programs should be implemented.

26. Additional guidance for the prevention and control of fugitive emissions from storage tanks is provided in the **EHS Guidelines for Crude Oil and Petroleum Product Terminals**.

1.1.4 Waste Management

27. Non-hazardous and hazardous wastes potentially generated at LNG facilities include general office and packaging wastes, waste oils, oil-contaminated rags, hydraulic fluids, used batteries, empty paint cans, waste chemicals and used chemical containers, used filters, spent sweetening and dehydration media (e.g., molecular sieves) and oily sludge from oil-water separators, spent amine from acid gas removal units (if present), scrap metals, and medical waste, among others.

28. Waste materials should be segregated into non-hazardous and hazardous wastes and considered for re-use/recycling prior to disposal. A waste management plan should be developed that contains a waste tracking mechanism from the originating location to the final waste reception location. Storage, handling, and disposal of hazardous and nonhazardous waste should be conducted in a way consistent with good EHS practice for waste management, as described in the **General EHS Guidelines**.

1.1.5 Noise

29. The main noise emission sources in LNG facilities include pumps, compressors, generators and their drivers, compressor suction/discharge, recycle piping, air dryers, heaters, air coolers at liquefaction facilities, vaporizers used during regasification, and general loading/unloading operations of LNG carriers/vessels. Guidance on acceptable levels and general recommendations for prevention and control of noise are described in the **General EHS Guidelines**.

1.1.6 LNG Transport

30. Common environmental issues related to vessels and shipping (e.g., hazardous materials management, wastewater and other effluents, air emissions, and solid waste generation and management related to LNG tankers/carriers), and recommendations for their management are covered in the **EHS Guidelines for Shipping**. Emissions from tugs and LNG vessels, especially where the jetty is within close proximity to the coast, may represent an important source affecting air quality.

31. LNG vessel design, construction, and operations should comply with international standards and codes[16] relating to hull requirements (e.g., double hulls with separation distances between each layer), cargo containment, pressure/temperature controls, ballast tanks, safety systems, fire protection, and crew

[15] See U.S. CFR Title 49, Part 193: Liquefied Natural Gas Facilities: Federal Safety Standards (2006), European Standard (EN) 1473: Installation and Equipment for Liquefied Natural Gas—Design of Onshore Installations (2016), and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2016).

[16] Examples of international standards and codes include the International Maritime Organization's (IMO) International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, known as the International Gas Carrier Code (IGC Code). Further guidance is provided in the standards, codes of practice, principles, and guidelines issued by SIGTTO, available at www.sigtto.org.

training, among other issues.[17] Specific recommendations to mitigate RPT, a physical explosion caused by rapid vaporization of LNG upon coming in contact with water that doesn't involve combustion or burning, include the following:

- The pressure rating of the actual LNG cargo tanks should be maximized.
- The LNG cargo tanks' pressure relief systems should actuate quickly to relieve large volumes of vapor that can be generated by an RPT event.

32. LNG can be transported by road tankers or trailers to end users and LNG fueling facilities. Potential risks associated with LNG road transport are traffic accidents, BOG build-up, and leakages from the tank. BOG build-up during road tanker transport is a critical factor that should be addressed properly. LNG road tankers or trailers should be constructed as double-walled, with a combined vacuum and insulation system to keep the cryogenic liquid cool during transportation. Additional guidance on the transport of Hazardous Materials is provided in Section 3.5 of the **General EHS Guidelines**.

1.1.7 LNG Fueling

33. The design, siting, construction, installation, spill containment, and operation of containers, pressure vessels, pumps, vaporization equipment, buildings, structures, and associated equipment used for the storage and dispensing of LNG as engine fuel for vehicles of all types should follow internationally recognized standards.[18]

34. Additional guidance for the management of EHS issues related to retail fueling operations (such as wastewater and other effluents, air emissions, and solid waste generation and management) is provided in the **EHS Guidelines for Retail Petroleum Networks**.

1.2 Occupational Health and Safety

35. Occupational health and safety issues should be considered as part of a comprehensive hazard or risk assessment, including, for example, a hazard identification study (HAZID), hazard and operability study (HAZOP), or other risk assessment studies. The results should be used for health and safety management planning, in the design of the facility and safe working systems, and in the preparation and communication of safe working procedures.

36. Facilities should be designed to eliminate or reduce the potential for injury or risk of accident and should take into account prevailing environmental conditions at the site location, including the potential for extreme natural hazards such as earthquakes or hurricanes.

37. Health and safety management planning should demonstrate: that a systematic and structured approach to managing health and safety will be adopted and that controls are in place to reduce risks to

[17] LNG transport ships are required to have an "Onboard Emergency Plan," as established by international regulations (Rule 26 of Appendix I of the MARPOL 73/78 agreement). LNG Facilities' contingency plans should cover loading/unloading operations, and, as recommended by the IMO, should include communications and coordination between the "ship and shore."

[18] For example: NFPA 52 Vehicular Gaseous Fuel Systems Code (2013) and EN 13645: Installations and Equipment for LNG—Design of Onshore Installations with a Storage Capacity Between 5 metric tons and 200 metric tons (2002).

the lowest practicable level; that staff is adequately trained; and that equipment is maintained in a safe condition. The formation of a health and safety committee for the facility is recommended.

38. A formal Permit to Work (PTW) system should be developed for the facilities. The PTW will ensure that all potentially hazardous work is carried out safely and ensures effective authorization of designated work, effective communication of the work to be carried out, including hazards involved, and safe isolation procedures to be followed before commencing work. A lockout/tagout procedure for equipment should be implemented to ensure that all equipment is isolated from energy sources prior to maintenance or removal.

39. The facilities should be equipped, at a minimum, with an appropriate number of specialized first-aid providers (industrial pre-hospital care personnel) and the means to provide short-term, remote patient care. Depending on the number of personnel present and complexity of the facility, provision of an on-site medical unit and health care professional should be considered. In specific cases, telemedicine facilities may be an alternative option.

40. General facility design and operation measures to manage principal risks to occupational health and safety are provided in the **General EHS Guidelines**. General guidance for construction and decommissioning activities is also provided, along with guidance on health and safety training, personal protective equipment (PPE), and the management of physical, chemical, biological, and radiological hazards common to all industries.

41. Occupational health and safety issues associated with LNG facilities operations include the following:

- Fires and explosions
- Roll-over
- Contact with cold surfaces
- Chemical hazards
- Confined spaces

42. Occupational health and safety impacts and recommendations applicable to LNG transport by ships are covered in the **EHS Guidelines for Shipping**.[19]

1.2.1 Fires and Explosions

43. Fire and explosion hazards at LNG facilities may result from the presence of combustible gases and liquids, oxygen, and ignition sources during loading and unloading activities, and/or leaks and spills of flammable products. Possible ignition sources include sparks associated with the buildup of static electricity,[20] lightning, and open flames. The accidental release of LNG may generate the formation of an

[19] Construction and equipment of ships carrying liquefied gases in bulk and gas carriers need to comply with the requirements of the IGC Code, published by the IMO. Further guidance is provided in the standards, codes of practice, principles, and guidelines issued by SIGTTO.

[20] Static electricity may be generated by liquids moving in contact with other materials, including pipes and fuel tanks during loading and unloading of product. In addition, water mist and steam generated during tank and equipment cleaning can become electrically charged, in particular with the presence of chemical cleaning agents.

evaporating liquid pool, potentially resulting in a pool fire and/or the dispersion of a cloud of natural gas from pool evaporation.

44. In addition to recommendations for hazardous materials and oil management and emergency preparedness and response provided in the **General EHS Guidelines**, the following measures are specific to LNG facilities:

- Design, construct, and operate LNG facilities according to internationally recognized standards and practices[21] for the prevention and control of fire and explosion hazards, including provisions for safe distances between tanks in the facility and between the facility and adjacent buildings.[22]
- Implement safety procedures for loading and unloading of the product to transport systems (e.g., rail and tanker trucks, and vessels[23]), including use of fail-safe control valves and ESD equipment.
- Prepare a formal fire response plan supported by the necessary resources and provide fire training and response as part of workforce health and safety induction/training. Training should include the use of fire suppression equipment and evacuation, with advanced fire safety training provided to a designated firefighting team. Procedures may include coordination activities with local authorities or neighboring facilities. Further recommendations for emergency preparedness and response are addressed in the **General EHS Guidelines**.
- Prevent potential ignition sources by ensuring:
  - Proper grounding to avoid static electricity buildup and lightning hazards (including procedures for the use and maintenance of grounding connections).[24]
  - Use of intrinsically safe electrical installations and non-sparking tools.[25]
  - Implementation of permit systems and formal procedures for conducting any hot work during maintenance activities,[26] including proper tank cleaning and venting.
  - Application of hazardous area zoning for electrical equipment in design.
- Properly equip facilities with fire detection and suppression equipment that meets internationally recognized technical specifications for the type and amount of flammable and combustible materials stored at the facility. Examples of fire suppression equipment may include

[21] An example of good practice includes the U.S. NFPA Code 59A: Standard for the Production, Storage, and handling of Liquefied Natural Gas (LNG) (2016) and EN 1473 (2016). Further guidance to minimize exposure to static electricity and lightening is available in American Petroleum Institute Recommended Practice: Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents (2003).

[22] If adequate spacing between the areas cannot be ensured, consider other risk mitigation measures, such as blast walls, to separate process areas from other areas of the facility and/or strengthening of buildings.

[23] See Liquefied Gas Handling Principles on Ships and in Terminals—3rd edition (2000), Society of International Gas Tanker and Terminal Operators Ltd (SIGGTO) and U.S. CFR Title 33, Part 127: Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas, and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas.

[24] For example, see Chapter 20, ISGOTT (2006).

[25] For example, see Chapter 19, ISGOTT (2006).

[26] Control of ignition sources is especially relevant in areas of potential flammable vapor-air mixtures, such as within vapor space of tanks, within vapor space of rail/truck tankers during loading/unloading, near vapor disposal/recovery systems, near discharge vents of atmospheric tanks, in proximity to a leak or spill.

mobile/portable equipment such as fire extinguishers and specialized vehicles. Fixed fire suppression may include the use of foam towers and large flow pumps. A combination of automatic and manual fire alarm systems should be present. When active fire protection systems are installed, they should be located to enable rapid and effective response. The installation of halon-based fire systems is not considered good industry practice and should be avoided. Fixed systems may also include foam extinguishers attached to tanks, and automatic or manually operated fire protection systems at loading/unloading areas. Water is not suitable for fighting LNG fires, as it increases the vaporization rate of LNG.[27]

- Locate all fire protection systems in a safe area of the facility, protected from the fire by distance or by fire walls.
- Avoid explosive atmospheres in confined spaces by making spaces inert.
- Protect accommodation areas by distance or by firewalls. The ventilation air intakes should prevent smoke from entering accommodation areas.
- Implement safety procedures for loading and unloading of product to transport systems (e.g., ship tankers, rail and tanker trucks, and vessels[28]), including use of fail-safe control valves and emergency shutdown equipment/structures.[29]
- Provide fire safety training and response as part of workforce health and safety induction/training, including training in the use of fire suppression equipment and evacuation, with advanced fire safety training provided to a designated firefighting team.

1.2.2 Roll-over

45. Storage of large quantities of LNG in tanks may lead to a phenomenon known as "roll-over." The potential for rollover in LNG storage tanks arises when separate layers of LNG of differing densities exist within the tank. If these layers are mixed inappropriately, a rapid release of LNG vapors and a rapid rise in pressure could occur that, in the absence of properly operating safety-vent valves, could cause structural damage to the tank. Rollover can occur due to: fill-induced stratification caused by loading LNG of varying densities into the storage tank; or auto-stratification if a sufficient quantity of nitrogen exists in the LNG such that it boils off preferentially and results in a reduced liquid bulk density. Recommended measures to prevent roll-over or minimize its consequences include the following:[30]

- Measure stratification by monitoring LNG storage tanks for pressure, density, and temperature all along the liquid column.
- Prevent stratification by installing a system to recirculate the LNG within the tank and/or installing multiple loading points at different tank levels to allow for the distribution of LNG with different densities within the tank.

[27] Good practice examples include the U.S. NFPA Standard 59A or other equivalent standards.

[28] An example of good industry practice for loading and unloading of tankers includes ISGOTT.

[29] Good practice examples include the U.S. NFPA Standard 59A or other equivalent standards.

[30] See "Rollover in LNG Storage Tanks 2nd Edition: 2015: Summary Report by the GIIGNL Technical Study Group on the Behaviour of LNG in Storage", http://www.giignl.org/sites/default/files/PUBLIC_AREA/Publications/rollover_in_lng_storage_tanks_public_document_low-res.pdf

- Install pressure safety valves designed to accommodate roll-over conditions and prevent damage to the tank.

1.2.3 Contact with Cold Surfaces

46. Storage and handling of LNG may expose personnel to contact with very low-temperature product. Plant equipment that can pose an occupational risk due to low temperatures should be adequately identified and protected (e.g., insulated) to reduce accidental contact with personnel. Training should be provided to educate workers handling or dispensing LNG (e.g., at LNG fuel stations) regarding the hazards of contact with cold surfaces (e.g., cold burns). PPE (e.g., gloves, insulated clothing) should be provided.

1.2.4 Chemical Hazards

47. The design of LNG facilities should reduce exposure of personnel to chemical substances, fuels, and products containing hazardous substances. For each chemical used, a Safety Data Sheet (SDS) should be available and readily accessible at the facility. A general hierarchical approach to the prevention of impacts from chemical hazards is provided in the **General EHS Guidelines**.

48. Facilities should be equipped with a reliable system for gas detection that allows the source of release to be isolated and the inventory of gas that can be released to be reduced. Blowdown of pressure equipment should be initiated to reduce system pressure and consequently reduce the release flow rate. Gas detection devices should also be used to authorize entry and operations into confined spaces.

49. Liquefaction facilities with gas treatment operations may have the potential for releases of hydrogen sulfide (H_2S). Wherever H_2S gas may accumulate, the following measures should be considered:

- Development of a contingency plan for H_2S release events, including appropriate aspects from evacuation to resumption of normal operations.
- Installation of monitors set to activate warning signals whenever detected concentrations of H_2S exceed 7 milligrams per cubic meter (mg/m^3).[31] The number and location of monitors should be determined based on an assessment of plant locations prone to H_2S emissions and occupational exposure.
- Provision of personal H_2S detectors to workers in locations of high risk of exposure along with self-contained breathing apparatus and emergency oxygen supplies that are conveniently located to enable personnel to safely interrupt tasks and reach a temporary refuge or safe haven.
- Provision of adequate ventilation of occupied buildings and of adequate safety systems (e.g., airlocks, ventilation shut down by gas detection) to avoid accumulation of H_2S gas.
- Workforce training in safety equipment use and response in the event of a leak.

1.2.5 Confined Spaces

50. Confined space hazards, as in any other industry sector, are potentially fatal to workers. Confined space entry by workers and the potential for accidents may vary among LNG terminal facilities depending

[31] ACGIH Threshold Limit Value–Short-Term Exposure Limit.

on design, on-site equipment, and infrastructure. Confined spaces may include storage tanks, secondary containment areas, and stormwater/wastewater management infrastructure. Facilities should develop and implement confined space entry procedures as described in the **General EHS Guidelines**.

1.3 Community Health and Safety

51. Community health and safety impacts during the construction and decommissioning of facilities are common to those of most other industrial facilities and are discussed in the **General EHS Guidelines**.

52. Community health and safety impacts during the operation of LNG facilities or transport of LNG are related to potential accidental natural gas leaks, in either liquid or gas form. Flammable gas or heat radiation and overpressure may potentially impact community areas outside the facility boundary, although the probability of large-magnitude events directly associated with storage operations in well-designed and well-managed facilities is usually negligible.[32] The layout of an LNG facility and the separation distance between the facility and the public and/or neighboring facilities outside the LNG plant boundary should be based on an assessment of risks from LNG fire (thermal radiation protection), vapor cloud (flammable vapor-dispersion protection), or other major hazards.

53. LNG facilities should prepare an emergency preparedness and response plan that considers the role of communities and community infrastructure in the event of an LNG leak or explosion. Ship traffic, including at loading and unloading jetties, associated with LNG facilities should be considered, with respect to local marine traffic patterns and activities. Location of ship loading/unloading facilities should also consider the presence of other shipping lanes and other marine activities in the area (e.g., fishing, recreation). Drivers of LNG tankers and trailers should be trained on road safety and emergency response plans. Additional information on the elements of emergency plans is provided in the **General EHS Guidelines**. General shipping safety management strategies also applicable to LNG transport by sea are covered in the **EHS Guidelines for Shipping**.

1.3.1 Security

54. Unauthorized access to facilities should be avoided by perimeter fencing surrounding the facility and controlled access points (guarded gates). Public access control should be applied. Adequate signs and closed areas should establish the areas where security controls begin at the property boundaries. Vehicular traffic signs should clearly designate the separate entrances for trucks/deliveries and visitor/employee vehicles. Means for detecting intrusion (for example, closed-circuit television) should be considered. To maximize opportunities for surveillance and minimize possibilities for trespassers, the facility should have adequate lighting.

[32] The assessment and control of risks to the community should follow recognized international standards, for example, EN 1473. The definition of protection distances for LNG storage and other facilities should be considered for adoption—for example, U.S. CFR, Title 49, Part 193.16—to protect the surrounding areas.

2. PERFORMANCE INDICATORS MONITORING

2.1 Environment

2.1.1 Emission and Effluent Guidelines

55. Air emissions from LNG facilities should be controlled through the application of techniques described in Section 1.1 of these Guidelines. Effluent guidelines are described in Table 1. Guideline values for process effluents in this sector are indicative of good international industry practice, as reflected in relevant standards of countries with recognized regulatory frameworks. Combustion source emissions guidelines associated with heat recovery, steam and/or power-generation activities from sources with a capacity equal to or lower than 50 MWth are addressed in the **General EHS Guidelines**, with larger power source emissions addressed in the **EHS Guidelines for Thermal Power.**

TABLE 1. EFFLUENT LEVELS FOR LNG FACILITIES

PARAMETER	GUIDELINE
Hydrotest water	Treatment and disposal as per guidance in Section 1.1 of this document. For discharge to surface waters or to land: ○ Total hydrocarbon content: 10 mg/L ○ pH: 6–9 ○ BOD: 25 mg/L ○ COD: 125 mg/L ○ TSS: 35 mg/L ○ Phenols: 0.5 mg/L ○ Sulfides: 1 mg/L ○ Priority pollutant metals[a] (total): 5 mg/L Chlorides:[b] 600 mg/L (average), 1200 mg/L (maximum)
Contaminated storm water drainage	Contaminated storm water runoff should be treated through an oil/water separation system able to achieve oil & grease concentration not exceeding 10 mg/L.
Cooling or cold water	The effluent should result in a temperature change of no more than 3°C at the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors, and assimilative capacity. Free chlorine (total residual oxidant in estuarine/marine water) concentration in cooling/cold water discharges (to be sampled at point of discharge) should be maintained below 0.2 parts per million (ppm).
Sewage	Treatment as per guidance in the General EHS Guidelines, including discharge requirements. Provision of facilities to receive LNG tanker effluents may be required (see EHS Guidelines for Ports and Harbors).

Notes:
[a] These are: Ag, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se, Tl, Zn.
[b] For discharge to freshwater.

2.1.2 Resource Use and Energy Consumption

56. Table 2 provides examples of resource and energy consumption indicators in this sector. Industry benchmark values are provided for comparative purposes only and individual projects should target continual improvement in these areas. They are presented here as a point of reference for comparison to enable facility managers to determine the relative efficiency of the project and can also be used to assess performance changes over time.

TABLE 2. ENERGY CONSUMPTION

PARAMETER	UNIT	INDUSTRY BENCHMARK
Energy consumption—LNG liquefaction process	kWh/ton LNG	275–400[a]

Notes:
[a] UNECE, 2014.

2.1.3 Environmental Monitoring

57. Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

58. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

2.2 Occupational Health and Safety

2.2.1 Occupational Health and Safety Guidelines

59. Occupational health and safety performance should be evaluated against internationally published exposure guidelines, examples of which include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[33] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[34] Permissible Exposure Limits (PELs)

[33] http://www.acgih.org/store/
[34] http://www.cdc.gov/niosh/npg/

published by the Occupational Safety and Health Administration of the United States,[35] Indicative Occupational Exposure Limit Values published by European Union member states,[36] or other similar sources.

2.2.2 Accident and Fatality Rates

60. Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. The accident and fatality rates of the specific facility may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g., U.S. Bureau of Labor Statistics and U.K. Health and Safety Executive).[37]

2.2.3 Occupational Health and Safety Monitoring

61. The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[38] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents, diseases and dangerous occurrences, and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[35] http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

[36] https://osha.europa.eu/en/legislation/directives/exposure-to-chemical-agents-and-chemical-safety/osh-related-aspects/council-directive-91-414-eec

[37] http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

[38] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

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ANNEX A. GENERAL DESCRIPTION OF INDUSTRY ACTIVITIES

62. Liquefying natural gas allows a significant volume reduction, which creates the ability to store and transport large liquefied natural gas (LNG) volumes by ship. The LNG chain includes the following phases of activities:

- Phase 1: Natural gas production (upstream activities and facilities)
- Phase 2: Transportation of natural gas to processing/liquefaction plants
- Phase 3: Treatment of natural gas (dehydration, removal of hydrogen sulfide (H_2S), etc.)
- Phase 4: Natural gas liquefaction
- Phase 5: Loading of LNG in LNG carrier ships and transportation to the receiving terminals
- Phase 6: Unloading and storage of LNG in the receiving terminals
- Phase 7: Regasification of LNG by heat exchange
- Phase 8: Distribution of natural gas to the network through gas transmission pipelines and to LNG Fueling facilities for road and rail transportation, and non-road applications (mining trucks)

63. Raw natural gas should be "conditioned" before its use to remove heavier hydrocarbons and undesired components or impurities. Gas conditioning can take place in separate or stand-alone facilities or can be integrated in the LNG liquefaction plant, and typically includes the extraction of heavier hydrocarbons such as liquefied petroleum gas and natural gas liquids, such as propane and butane. The conditioned (methane-rich) gas is then treated in the LNG liquefaction facilities. To be transported, the LNG is cooled to approximately –162°C, where it condenses to a liquid at atmospheric pressure reducing to approximately 1/600 of its original volume and reaching a density of 420 to 490 kilograms per cubic meter (kg/m^3).

A.1 Natural Gas Liquefaction

64. A typical LNG base load liquefaction plant flow scheme is shown in Figure A.1. The process and utility requirement depends on site conditions, feed gas quality, and product specification. In a typical scheme, the feed gas is delivered at high pressure (up to 90 bar) from upstream gas fields via pipelines, and any associated condensate is stabilized and removed. The gas is metered and its pressure controlled to the design operating pressure of the plant.

65. The gas is pretreated to remove any impurities that interfere with processing or are undesirable in the final products. These treatments include sweetening (removal of acid gases and sulfur compounds—for example, CO_2, H_2S, and mercaptans, removal of mercury and other trace contaminants, as needed) and dehydration (removal of water).

66. The dry sweet gas is then cooled by refrigerant streams to separate heavier hydrocarbons. The treated gas is subjected to multiple cooling stages by indirect heat exchange with one or more refrigerants, whereby the gas is progressively reduced in temperature until complete liquefaction occurs. The pressurized LNG is further expanded and subcooled in one or more stages to facilitate storage at slightly above atmospheric pressure. Flashed vapors and BOG are typically recycled within the process. The resulting LNG is stored in atmospheric tanks ready for export by ship.

67. Heavier hydrocarbons that may be separated during cooling are fractionated and recovered. Ethane is sometimes reinjected into the gas stream to be liquefied. Propane and butane can either be reinjected or exported as LPG products and pentane (or heavier components) can be exported as a gasoline product.

68. Liquefaction processes mainly use mechanical refrigeration, in which heat is transferred from the natural gas, through exchanger surfaces, to a separate closed-loop vapor-compression refrigeration system. A number of different LNG processes have been developed and the most common ones include:

- Cascade, in which a number of separate refrigerant loops are used, with different single-component fluids, such as propane, ethylene, and methane.
- Mixed refrigerant, which uses a mixture of nitrogen and light hydrocarbons.

69. Key utilities required to support the processing units include the following:

- Fuel gas (derived from the process streams) to generate electric power
- Cooling medium (e.g., water, air)
- Heating medium (steam or hot oil system)

A.2 LNG Transport

70. LNG is transported from the liquefaction plant site to regasification terminals through specially designed LNG carriers having a typical capacity of 80,000 m^3 up to 260,000 m^3. Onboard tanks function as large thermos-type containers (pseudo-dewar), which enable the LNG to remain as a liquid for the duration of transport. A very small amount of gas is produced in the tanks and is collected to prevent a gradual buildup in pressure and can be used as the carrier's fuel. There are four containment systems, constantly monitored for the presence of gas and temperature change, in use for new LNG carriers:[39]

- Two self-supporting type designs:
  - Spherical (Moss) tank
  - Prismatic tank
- Two membrane-type designs (TGZ Mark III and GT96). Membrane tanks use two flexible steel membranes (primary and secondary) to contain the cargo.

A.3 LNG Onshore Regasification Terminal

71. The LNG regasification terminals typically consist of the following systems:

- LNG unloading system, including jetty and berth
- LNG storage tank(s)
- In-tank and external LNG pumps

[39] Relevant and detailed characteristics of tanks are covered in the guidance documents and design specifications developed by SIGTTO.

- Vapor-handling system
- LNG vaporizers

72. LNG is transferred to unloading lines and onto onshore LNG tanks by the ship pumps. During ship unloading, the vapor generated in the storage tank by displacement is returned to the ship's cargo tanks via a vapor return line and arm, maintaining a positive pressure in the ship. One or more large-capacity tanks are installed for receiving and storing LNG.

73. During normal operation, BOG is produced in the tanks and liquid-filled lines by heat transfer from the surroundings. BOG is typically collected to be recondensed in the LNG stream. During ship unloading, the quantity of vapor generated is higher. From the compressor suction drum, vapor is routed to the vapor return lines to the ship or to the BOG compressors. The vapor that is not returned to the ship is typically compressed and directed to the recondenser.

74. LNG from the storage tanks is sent by the in-tank pumps to the recondenser. The BOG generated during plant operation is also routed to this vessel, where it is mixed with the subcooled LNG and condensed.

75. Multistage high-head send-out pumps take the LNG from the recondenser and supply it to the vaporizers, where the heat exchange between the LNG and a heating medium allows vaporization of the high-pressure LNG, and the gas generated is sent directly to the export line. The most common types of vaporizers are as follows:

- ORVs, which use seawater to heat and vaporize the LNG.
- SCVs, which use burners fed by send-out gas to generate heat for vaporization.
- Shell and tube (or intermediate fluid) vaporizers, where an external source of heat is available.

A.4 Flare and Vent Systems

76. In case of extreme turndown or emergency conditions, BOG could be generated in quantities that exceed the capacity of the recondenser. In this case, BOG is sent to the atmosphere through flaring or venting. If emergency venting is implemented, consideration should be given to the cold methane that can slump after discharge from a vent, to prevent the cold methane from reaching the lower flammability limit.

A.5 LNG Offshore Receiving Terminal

77. Following are the design types of offshore LNG Facilities:

- Gravity-based structures (GBS)
- Floating storage regasification units (FSRUs)
- Floating regasification units (FRUs)
- Mooring systems with regasification

78. A GBS is a fixed concrete structure laying on the sea floor with all plant facilities located on top of the GBS.

79. An FSRU is an LNG carrier ship modified to include the regasification systems. They are floating structures moored to the seabed via a turret mooring system. The systems required for the LNG pumping, vaporization, BOG handling, and natural gas export to shore are located on the deck of the FSRU.

80. The FRU concept is based on the conversion of a crude oil carrier, which is modified to provide a platform for the regasification process and to enable mooring and LNG offloading from the LNG carriers. The FRU has no or limited LNG storage, so the LNG received from the carrier is instantly vaporized and transferred. A large gas storage volume also enables the unit to function as a peak-shaving facility.

81. The mooring systems with regasification can consist of the following:

- A single-point mooring (SPM) tower, in which the topsides regasification facilities are installed on a fixed tower structure. The LNG carrier should be moored via a rotating arm structure on the fixed tower. The carrier slowly discharges LNG to the SPM tower, where the LNG is simultaneously vaporized and transferred through the gas pipeline.
- A disconnectable riser turret mooring, which is a mooring and offloading system enabling high-pressure discharge from an LNG carrier with an on-board regasification plant.

A.6 LNG Fueling Facilities

82. LNG fueling stations generally receive their LNG supply from a liquefaction plant via tanker truck designed to distribute cryogenic fuels. At the fueling site, LNG is offloaded into the facility's storage system. In most LNG stations, the fuel passes through a pump to an ambient air vaporizer that serves as a heat exchanger. In this vaporizer, the temperature of the LNG is increased. The pressure increases at these temperatures, but the fuel remains a liquid. This process is called conditioning. After conditioning, LNG is stored in large cryogenic vessels that can be configured horizontally or vertically, and are typically found in capacities of 30 to 100m^3. When needed, LNG is dispensed as a liquid into cryogenic tanks onboard the vehicle, at pressures up to 20 bar.

Figure A.1. Liquefied Natural Gas Production