Environmental, Health, and Safety Guidelines for Liquefied Natural Gas (LNG) Facilities

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[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/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

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. 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. 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

The EHS Guidelines for Liquefied Natural Gas (LNG) Facilities include information relevant to LNG base load liquefaction plants, transport by sea, and regasification and peak shaving terminals. For coastal LNG facilities including harbors, jetties and in general coastal facilities (e.g. coastal terminals marine supply bases, loading / offloading terminals), additional guidance is provided in the EHS Guidelines for Ports, Harbors, and Terminals. For EHS issues related to vessels, guidance is provided in the EHS Guidelines for Shipping. Issues related to LPG/Condensate production and storage in Liquefaction plant are not covered In this Guideline. This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management
Section 2.0 — Performance Indicators and Monitoring
Section 3.0 — References
Annex A — General Description of Industry Activities

[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.

1.0 Industry-Specific Impacts and Management

This section provides a summary of EHS issues associated with LNG 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 most large industrial facilities during the construction phase is provided in the **General EHS Guidelines**.

1.1 Environment

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:

- Threats to aquatic and shoreline environments
- Hazardous material management
- Wastewater
- Air emissions
- Waste management
- Noise
- LNG transport

Threats to Aquatic and Shoreline Environments

Construction and maintenance dredging, disposal of dredge spoil, construction of piers, wharves, breakwaters, and other water-side structures, and erosion may lead to short and long-term impacts on aquatic and shoreline habitats. Direct impacts may include the physical removal or covering of sea floor, shore, or land-side habitat while indirect impacts may result from changes to water quality from sediment suspension or discharges of stormwater and wastewater. Additionally, the discharge of ballast water and sediment from ships during LNG terminal loading operations may result in the introduction of invasive aquatic species. For LNG facilities located near the coast (e.g. coastal terminals marine supply bases, loading / offloading terminals), guidance is provided in the **EHS Guidelines for Ports, Harbors, and Terminals**.

Hazardous Materials Management

Storage, transfer, and transport of LNG may result in leaks or accidental release from tanks, pipes, hoses, and pumps at land installations and on LNG transport vessels. 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.

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:

- LNG storage tanks and components (e.g. pipes, valves, and pumps) should meet international 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 international standards may include provisions for overfill protection, secondary containment, metering and flow control, fire protection (including flame arresting devices), and grounding (to prevent electrostatic charge).[2]
- 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,

[2] See US Code of Federal Regulations (CFR) 4049 CFR 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 (1997), and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (20012006).

connectors, and valves).[3] 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, adherence to no-smoking and no-naked light policies for personnel and visitors.[4]

Spills

LNG is a cryogenic liquid (–162°C [–259°F]) that is not flammable in liquid form. However, boil-off gas (methane) forms as the LNG warms, and under 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 a methane vapor cloud which 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[5]) could result in a sudden phase change known as a Rapid Phase Transition (RPT)[6].

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;
- Develop a formal spill prevention and control plan that addresses significant scenarios and magnitude of releases. The plan should be supported by the necessary resources and training. Spill response equipment should be conveniently available to address all types of spills, including small spills[7];
- Spill control response plans should be developed in coordination with the relevant local regulatory agencies;
- Facilities should be equipped 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 ESDs can be rapidly activated, thereby minimizing the inventory of gas releases.
- An Emergency Shutdown and Detection (ESD/D) system should be available to initiate automatic transfer shutdown actions in case of a significant LNG leak;
- For unloading / loading activities involving marine vessels and terminals, preparing and implementing spill prevention procedures for tanker loading and off-loading according to applicable international standards and guidelines which specifically address advance communications and planning with the receiving terminal;[8]

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3 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.

4 Examples of good practice for LNG loading and unloading include Liquefied Gas Handling Principles on Ships and in Terminals - 3rd edition (2000), Society of International Gas Tanker and Terminal Operators Ltd (SIGTTO) and US Code of Federal Regulations (CFR) 33 CFR Part 127: Waterfront facilities handling liquefied natural gas and liquefied hazardous gas.

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

6 A potentially significant environmental and safety hazard from LNG shipping is related to Rapid Phase Transition (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.

7 Small spills of LNG or refrigerant are unlikely to need spill response equipment for manual response, since they will evaporate quickly.

8 See US EPA Code of Federal Regulations (CFR) 4049 CFR Part 193: Liquefied Natural Gas Facilities: Federal Safety Standards (2006) and European Standard (EN) 1473: Installation and Equipment for Liquefied Natural Gas -

- Ensuring 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) in the event of a sudden release;
- 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];
- Material selection for piping and equipment that can be exposed to cryogenic temperatures should follow international design standards;[10]
- In case of a gas release, safe dispersion of the released gas should be allowed, 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. covering with expanding foam; and
- The facility drainage system should be designed 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.

Wastewater

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

The use of water for process cooling at LNG liquefaction facilities and for revaporization heating at LNG receiving terminals may result in significant water use and discharge streams. Recommendations to control cooling and cold 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 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[11]. 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 and cooling of the thermal plume to ensure that the temperature is within 3 degrees Celsius of ambient temperature at the edge of the mixing zone or within 100 meters of the discharge point, as noted in Table 1 of Section 2.1 of this Guideline;
- 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.

Design of Onshore Installations (1997), and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2006)

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

[10] NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2001)

[11] 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.

Other Wastewater Streams

Other waste waters routinely generated at LNG facilities include process wastewater drainage, sewage waters, tank bottom water (e.g. from condensation in LNG storage tanks), fire water, equipment and vehicle wash waters, and general oily water. Pollution prevention and treatment measures that should be considered for these waste waters include:

- *Sewage:* Gray and black water from showers, toilets and kitchen facilities should be treated as described in the **General EHS Guidelines**.
- *Drainage and stormwaters:* 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. All process areas should be bunded to ensure drainage water flows into the closed drainage system and that uncontrolled 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. Stormwater 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. Stormwater runoff should be treated through an oil / water separation system able to achieve an oil and grease concentration of 10 mg/L, as noted in Section 2.1, Table 1 of this Guideline. Additional guidance on the management of stormwater is provided in the **General EHS Guideline.**
- *Firewater:* Firewater from test releases should be contained and directed to the facility drainage system or to a storage pond and wastewater treatment, 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 waste water 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 of 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

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 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.[12] Further recommendations for managing hydrotest

[12] Effluent discharge to surface waters should not result in significant impact on human health and sensitive habitats. A disposal plan that considers points of

water for pipelines are available in the two **EHS Guidelines for Onshore and Offshore Oil and Gas Development,** respectively.

Air Emissions

Air emissions (continuous or non-continuous) from LNG facilities include combustion sources for power and heat generation (e.g. for dehydration and liquefaction activities at LNG liquefaction terminals, and regasification activities at LNG receiving terminals), in addition to the use of compressors, pumps, and reciprocating engines (e.g. boilers, turbines, and other engines). Emissions resulting from flaring and venting, as well as from fugitive sources, may result from activities at both LNG liquefaction and regasification terminals. Principal gases 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).

For LNG plants with important combustion sources, 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 no adverse impacts to human health and the environment result.

All reasonable attempts should be made to maximize energy efficiency and design facilities to minimize energy use. The overall objective should be to reduce air emissions and evaluate cost-effective options for reducing emissions that are technically feasible. Additional recommendations on energy efficiency are addressed in the **General EHS Guidelines.**

Significant (>100,000 tons CO_2 equivalent per year) greenhouse gas (GHG) emissions from all facilities and support activities should be quantified annually as aggregate emissions in accordance with internationally recognized methodologies and reporting procedures.[13]

Exhaust Gases

Exhaust gas emissions produced by the combustion of natural gas or liquid hydrocarbons in turbines, boilers, compressors, pumps and other engines for power and heat generation, can be the most significant source of air emissions from LNG facilities. Air emission specifications should be considered during all equipment selection and procurement.

Guidance for the management of small 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.**

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 (WHR) / shell and tube vaporizers could be considered.

discharge, rate of discharge, chemical use and dispersion and environmental risk may be necessary. Discharges should be planned away from environmentally sensitive areas, with specific attention to high water tables, vulnerable aquifers, and wetlands, and community receptors, including water wells, water intakes, and agricultural land.

[13] Additional guidance on quantification methodologies can be found in IFC Guidance Note 3, Annex A, available at www.ifc.org/envsocstandards

[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.

Venting and Flaring

Flaring or venting is an important safety measure used at LNG facilities to ensure 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 (BOG)

After LNG liquefaction, stored LNG emits methane gas vapor, known as 'boil off gas' (BOG), due to heat 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

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 be based on their capacity to reduce gas leaks and fugitive emissions[15]. Additionally, leak detection and repair programs should be implemented.

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

Waste Management

Non-hazardous and hazardous wastes routinely 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, scrap metals, and medical waste, among others.

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**.

Noise

The main noise emission sources in LNG facilities include pumps, compressors, generators and 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.

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[15] See US EPA Code of Federal Regulations (CFR) 4049 CFR 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 (1997), and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2006)

Atmospheric conditions that may affect noise levels include humidity, wind direction, and wind speed. Vegetation, such as trees, and walls can reduce noise levels. Installation of acoustic insulating barriers can be implemented, where necessary. Maximum allowable log equivalent ambient noise levels that should not be exceeded and general recommendations for prevention and control of noise are described in the **General EHS Guidelines**.

LNG Transport

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.

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, crew training, among other issues[17]. Specific recommendations to mitigate Rapid Phase Transition (RPT) include the following:

- The pressure rating of the actual LNG cargo tanks should be maximized;
- The LNG cargo tanks pressure relief system should actuate as quickly as possible, in order to relieve the large volumes of vapor that can be generated by an RPT event.

1.2 Occupational Health and Safety

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.

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.

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 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.

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 /

[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 practices, principles and guidelines issued by the Society of International Gas Tanker and Terminal Operators (SIGTTO), available at www.sigtto.org.

[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".

tagout procedure for equipment should be implemented to ensure all equipment is isolated from energy sources before servicing or removal.

The facilities should be equipped, at a minimum, with 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 doctor should be considered. In specific cases, telemedicine facilities may be an alternative option.

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 and the management of physical, chemical, biological and radiological hazards common to all industries.

Occupational health and safety issues associated with LNG Facilities operations include the following:

- Fire and explosion
- Roll-over
- Contact with cold surfaces
- Chemical hazards
- Confined spaces

Occupational health and safety impacts and recommendations applicable to LNG transport by ships are covered in the **EHS Guidelines for Shipping**.[18]

Fires and Explosions

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[19], lightning, and open flames. The accidental release of LNG may generate the formation of an evaporating liquid pool, potentially resulting in a pool fire and / or the dispersion of a cloud of natural gas from pool evaporation.

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:

- LNG facilities should be designed, constructed, and operated according to international standards[20] 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;[21]
- Implementing safety procedures for loading and unloading of product to transport systems (e.g. rail and tanker trucks, and vessels[22]), including use of fail safe control valves and emergency shutdown and detection equipment (ESD/D);

[18] Construction and equipment of ships carrying liquefied gases in bulk and gas carriers need to comply with the requirements of the International Gas Carrier Code (IGC Code), published by the International Maritime Organisation (IMO). Further guidance is provided in the standards, codes of practices, principles and guidelines issued by the Society of International Gas Tanker and Terminal Operators (SIGTTO).

[19] 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 be come electrically charged, in particular with the presence of chemical cleaning agents.

[20] An example of good practice includes the US National Fire Protection Association (NFPA) Code 59A: Standard for the Production, Storage, and handling of Liquefied Natural Gas (LNG) (2006) and EN 1473. Further guidance to minimize exposure to static electricity and lightening is available in API Recommended Practice: Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents (2003).

[21] If adequate spacing between the areas cannot be ensured, blast walls should be considered to separate process areas from other areas of the facility and/or strengthening of buildings should be considered.

[22] See Liquefied Gas Handling Principles on Ships and in Terminals - 3rd edition (2000), Society of International Gas Tanker and Terminal Operators Ltd (SIGGTO) and US EPA Code of Federal Regulations (CFR) 33 CFR Part 127:

- Preparation of a formal fire response plan supported by the necessary resources and training, including training in the use fire suppression equipment and evacuation. 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**;
- Prevention of potential ignition sources such as:
  - Proper grounding to avoid static electricity buildup and lightning hazards (including formal procedures for the use and maintenance of grounding connections);[23]
  - Use of intrinsically safe electrical installations and non-sparking tools;[24]
  - Implementation of permit systems and formal procedures for conducting any hot work during maintenance activities,[25] including proper tank cleaning and venting,
  - Application of hazardous area zoning for electrical equipment in design;
- Facilities should be properly equipped 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 mobile / portable equipment such as fire extinguishers, and specialized vehicles. Fixed fire suppression may include the use of foam towers and large flow pumps. 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, but.[26]
- All fire systems should be located in a safe area of the facility, protected from the fire by distance or by fire walls;
- Explosive atmospheres in confined spaces should be avoided by making spaces inert;
- Protection of accommodation areas by distance or by fire walls. The ventilation air intakes should prevent smoke from entering accommodation areas;
- Implementation of safety procedures for loading and unloading of product to transport systems (e.g. ship tankers, rail and tanker trucks, and vessels[27]), including use of fail safe control valves and emergency shutdown equipment/structures.[28];
- Preparation of a fire response plan supported by the necessary resources to implement the plan;
- Provision of fire safety training and response as part of workforce health and safety induction / training, including training in the use fire suppression equipment and evacuation, with advanced fire safety training provided to a designated fire fighting team.

Roll-over

Storage of large quantities of LNG in tanks may lead to a phenomenon known as “roll-over”. Roll-over may occur if LNG stratifies into layers of different densities within the storage tank, resulting in pressures that, in the absence of properly operating safety-vent valves, could cause structural damage.

Waterfront facilities handling liquefied natural gas and liquefied hazardous gas, and NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (2006)

[23] For example, see Chapter 20, ISGOTT (1995).

[24] For example, see Chapter 19, ISGOTT (1995).

[25] 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.

[26] Good practice examples include the US National Fire Protection Association (NFPA) Standard 59A or other equivalent standards.

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

[28] Good practice examples include the US National Fire Protection Association (NFPA) Standard 59A or other equivalent standards.

Recommended measures to prevent roll over include the following:

- Monitor LNG storage tanks for pressure, density, and temperature all along the liquid column;
- Consider installation of a system to recirculate the LNG in within the tank;
- Install pressure safety valves for tanks designed to accommodate roll over conditions;
- Install multiple loading points at different tank levels to allow for the distribution of LNG with different densities within the tank to prevent stratification.

Contact with Cold Surfaces

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

Chemical Hazards

The design of the onshore facilities should reduce exposure of personnel to chemical substances, fuels, and products containing hazardous substances. Use of substances and products classified as very toxic, carcinogenic, allergenic, mutagenic, teratogenic, or strongly corrosive should be identified and substituted by less hazardous alternatives, wherever possible. For each chemical used, a Material Safety Data Sheet (MSDS) should be available and readily accessible on the facility. A general hierarchical approach to the prevention of impacts from chemical hazards is provided in the **General EHS Guidelines**.

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 enclosed spaces. 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 all necessary 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). 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 is 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 hydrogen sulfide gas;
- Workforce training in safety equipment use and response in the event of a leak.

Confined Spaces

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 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

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**.

Community health and safety impacts during the operation of LNG Facilities 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 managed facilities is usually negligible[29]. The layout of a 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.

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). 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.**

Security

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.

2.0 Performance Indicators and Industry Benchmarks

2.1 Environmental Performance

Emission and Effluent Guidelines

Effluent guidelines are described in Table 1. Air emissions from LNG facilities should be controlled through the application of techniques described in Section 1.1 of these Guidelines. 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

[29] 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. Code of Federal Regulations (CFR) 49, Part 193.16–to protect the surrounding areas

associated with steam and 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: o Total hydrocarbon content: 10 mg/L o pH: 6 - 9 o BOD: 25 mg/L o COD: 125 mg/L o TSS: 35 mg/L o Phenols: 0.5 mg/L o Sulfides: 1 mg/L o Heavy metals (total): 5 mg/L o Chlorides: 600 mg/L (average), 1200 mg/L (maximum)
Hazardous stormwater drainage	Stormwater runoff should be treated through an oil/water separation system able to achieve oil & grease concentration of 10 mg/L.
Cooling water	The effluent should result in a temperature increase of no more than 3° C at edge of the zone where initial mixing and dilution take place. Where the zone is not defined, use 100 m from point of discharge. 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 at 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).

Resource Use and Energy Consumption

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.

Environmental Monitoring

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.

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**.

Table 2. Resource and Energy Consumption		
Parameter	**Unit**	**Industry Benchmark**
Energy consumption of LNG transportation[1]	MJ/GJ gas per 100 km	19–20[1]
Energy consumption – regasification plants	MWe	20–30[2]
Water consumption - ORV systems[3]	m^3/hr	30,000

Notes:
[1] IEA, 1999
[2] Offshore GBS or floating regasification unit of 8 GSm^3/year
[3] Thermal delta of 5°C for a 8 GSm^3/year regasification plant

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[30] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[31] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[32] Indicative Occupational Exposure Limit Values published by European Union member states,[33] or other similar sources.

Accident and Fatality Rates

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. US Bureau of Labor Statistics and UK Health and Safety Executive)[34].

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[35] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

30 http://www.acgih.org/TLV/30 Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
31 Available at: http://www.cdc.gov/niosh/npg/
32 Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992
33 Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/
34 Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

35 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

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; and
- Phase 8: Distribution of natural gas to the network through gas transmission pipelines.

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 (LPG) and natural gas liquids (NGL) such as propane and butane. The conditioned gas (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 square meters (kg/m^2).

Natural Gas Liquefaction

A typical LNG base load liquefaction plant flow scheme is shown in Figure A1. 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.

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

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. The pressurized LNG is further expanded and subcooled in one or more stages to facilitate storage at slightly above atmospheric pressure. Flashed vapors and boil-off gas (BOG) are recycled within the process. The resulting LNG is stored in atmospheric tanks ready for export by ship.

Heavier hydrocarbons that may be separated during cooling are fractionated and recovered. Ethane is normally 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.

Liquefaction processes mainly use mechanical refrigeration, in which heat is transferred from the natural gas, through exchanger surfaces, to a separate closed-loop refrigerant fluid. The refrigerant loop uses the cooling effect of fluid expansion, requiring work input via a compressor. 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; and
- Mixed refrigerant, which uses a mixture of nitrogen and light hydrocarbons.

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

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

LNG Transport

LNG is transported from the liquefaction plant site to regasification terminals through specially designed LNG carriers having a typical capacity of 80,000 m3 up to 260,000 m3. 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 five containment systems, constantly monitored for the presence of gas and temperature change, in use for new LNG carriers:[36]

- 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.

LNG Onshore Regasification Terminal

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;
- Vapor handling system;
- LNG vaporizers

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.

During normal operation, BOG is produced in the tanks and liquid-filled lines by heat transfer from the surroundings. The 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 compressed and directed to the recondenser.

LNG from the storage tanks is sent by the in-tank pumps to the recondenser. The BOG generated during plant operation is also

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

routed to this vessel where it is mixed with the subcooled LNG and condensed.

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:

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

Flare and Vent Systems

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 slump after discharge to avoid the cold methane from reaching a grade above the lower flammability limit (LFL).

LNG Offshore Receiving Terminal

Following are the design types of offshore LNG Facilities:

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

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

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.

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.

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; and
- A disconnectable riser turret mooring (RTM), which is a mooring and offloading system enabling high pressure discharge from an LNG carrier with an on-board regasification plant.

Figure A.1: Liquefied Natural Gas Production