# EXPLOSIVE TRUTHS

## THE PERILS AND THE CATASTROPHIC POTENTIAL OF LNG

greenpeace.de

GREENPEACE

# Explosive Truths

## The perils and the catastrophic potential of LNG

Prepared by Equal Routes for Greenpeace Germany

**Equal Routes**
Equal Routes is an organization working to build a sustainable and equitable marine shipping sector focused on human rights, ocean health, and climate equity.
Learn more at: equalroutes.ca

**Authors**
Elissama Menezes – Co-founder and Director | Equal Routes
Andrew Dumbrille – Co-founder and Director | Equal Routes

**Data Collection and Review Support**
Breanna Bishop – Research Associate | Equal Routes

**Reviewers**
The authors are grateful to the reviewers of this report — any errors remain the authors' own.
György Dallos – Global Campaign Strategist, Climate & Energy | Greenpeace International
Mehmet Bulut – Senior Energy Analyst | Greenpeace International
Lisa Göldner – Deputy Campaign Area Lead & Lead Campaigner, European Fossil-Free Future Campaign | Greenpeace Germany
Eszter Matyas – Fossil-Free Future Campaigner | Greenpeace Central and Eastern Europe

**Imprint**

**Greenpeace e.V.** Hongkongstraße 10, 20457 Hamburg, T 040 30618-0 **Press Office** T 040 30618-340, F 040 30618-340, presse@greenpeace.de, greenpeace.de **Political Unit in Berlin** Marienstraße 19 – 20, 10117 Berlin, T 030 308899-0 **Responsible for content** Lisa Göldner **Text** Elissama Menezes, Andrew Dumbrille **Contributors** Breanna Bishop, Eszter Matyas, György Dallos, Mehmet Bulut, Lisa Göldner **Photos** Title, p. 16: Reginald Mathalone / Greenpeace; p 4: Hocine Zaourar / Getty Images; p 6 & 22: Tim Aubry / Greenpeace ; p 11: STR / AFP / Getty Images **Layout** Janitha Banda / Spektral3000
**12/2024**

# Table of contents

# 1. Executive Summary

**Liquefied "natural" gas (LNG), while often promoted as a supposedly cleaner alternative to coal and a way to diversify fossil gas supply, presents significant safety and environmental challenges that require a critical reevaluation of the role of LNG in the energy mix. This report prepared by Equal Routes for Greenpeace Germany highlights the continuous negative impacts of LNG operations, including a history of accidents, insufficient safety protocols, and growing methane and other greenhouse gas emissions, all of which underscoring the urgent need to halt LNG expansion and phase out fossil gas in favor of safer, renewable energy sources.**

**Opacity issues and failing safety protocols**
The report analyses 104 accidents linked to LNG industry facilities that occurred between 1944 and 2024 and exposes the risks associated with LNG operations. For example, the 2015 collision of the LNG carrier Al Oraiq, near Zeebrugge, Belgium, that occurred despite a relatively stricter European regulatory environment illustrates that even strict safety protocols can fail, leading to accidents that pose risks to both humans and the environment. Another example the report lists is a 2018 leakage incident at Cheniere Energy's Sabine Pass export facility located in Sabine Pass, Texas, United States, where investigators faced challenges in accessing relevant and detailed information from the company, highlighting issues of transparency and accountability in incident reporting.

This example underscores the disproportionate impact of fossil fuel infrastructure on vulnerable communities, as these facilities are often located near low-income and vulnerable populations who face heightened risks from industrial accidents and environmental hazards. According to the „Fossil Fuel Racism" report published by Greenpeace USA in 2021, communities of color in the US are 2.5 times more likely to live in proximity to fossil fuel facilities, which contributes to health disparities and environmental injustices. The leakage incident in Sabine Pass exemplifies the systemic issues of environmental racism that persist in the fossil fuel sector.

**Underestimated risks**
The report underscores that many LNG incidents are underreported, leading to a significant underestimation of the true scope and impacts of the accidents. It indicates that LNG spill dynamics, including vapor production and dispersion, remain poorly understood, complicating risk assessments and emergency response planning. Key risks to human safety include pool fires, jet fires, and vapor cloud explosions. The report notes that the actual impact of vapor cloud explosions at LNG facilities could be 15 to 20 times greater than the industry's current projections, indicating a severe underestimation of risks.

**First impacted: communities located in a 2 km radius around LNG facilities**
The report highlights that the handling, transportation, and storage of LNG pose significant challenges, particularly for communities located near LNG facilities and ports. Oftentimes these are communities whose members are already disproportionately struggling with socioeconomic disadvantages and marginalization. The lack of transparency regarding the circumstances surrounding accidents hides the true extent of the harm caused by the LNG industry and its potential for catastrophic disasters. The extensive gaps in information and the underreporting of incidents prevent the ability to evaluate and create effective emergency plans, presenting LNG safety systems unreliable. Moreover, the report points out that few ports have adequately implemented risk-based safety zones around LNG storage and bunkering areas, leading to potential safety gaps in densely populated regions. The risks of accidents affecting communities within a 2 km radius of LNG facilities are significant, as incidents can lead to severe environmental and health impacts.

The report emphasizes that cost-cutting measures within the LNG industry often lead to inadequate maintenance, insufficient training, and understaffing, which are significant contributors to accidents. Material failure and human error, each accounting for 40 % of incidents, underscore the


**Skikda, Algeria – The LNG plant in Skikda stands in ruins following a devastating explosion on January 19, 2004. The blast, Algeria's worst industrial disaster since independence, claimed at least 27 lives, injured many others, and severely impacted the nation's gas-dependent economy.**

risks associated with prioritizing financial savings over safety.

Additionally, the increasing intensity and frequency of extreme weather events, driven by the climate crisis, pose heightened risks to LNG facilities. As these events become more frequent and more intense – including due to continued and increased fossil gas consumption – the potential for accidents increases, complicating emergency response planning and further endangering nearby communities.

**Renewables: safer alternatives**
In contrast to LNG, renewable energy sources such as wind and solar power are a much safer alternative with no risks of similar catastrophic accidents with comparable disastrous consequences for workers, surrounding communities and the environment. Transitioning to these sustainable alternatives would not only mitigate safety risks but also align with global climate goals by reducing greenhouse gas emissions.

The evidence presented in this report advocates for a decisive shift away from LNG and fossil gas in general, emphasizing the need for a full transition to renewable energy sources that prioritize safety for workers and local communities and the protection of people's health and the environment. The frequency of LNG accidents, coupled with the industry's failure to adequately address safety concerns and the environmental risks posed by methane emissions, underscores the need to immediately stop LNG and fossil gas expansion and phase-out their use as fast as possible. The time has come to move beyond LNG and invest in a sustainable energy future that safeguards both people and the planet.

# 2. Key Research Findings

**High Human and Environmental Costs**
The LNG industry has a history of accidents with severe human and environmental consequences, which makes the case for immediately cancelling plans for new projects, and making safety and regulatory reform a critical priority for the already operational ones that must be phased out as soon as possible.

**Uncertainty in LNG Safety**
Significant gaps in safety measures and risk management amplify the potential for accidents, injuries, and environmental damage, revealing a fundamental lack of reliability in existing protocols. This highlights the insufficiency of international and national regulations in addressing LNG operational risks.

**Methane Leakage Risks**
Methane slip throughout the LNG supply chain has multiple threats, contributing to accidents and GHGs while compounding local air pollution challenges. Existing systems fail to adequately detect, report, or mitigate these leaks.

**Emergency Response Gaps**
A focus on reactive rather than preventive measures in LNG operations and regulations leaves critical vulnerabilities in risk mitigation and emergency response strategies. These gaps could have catastrophic consequences in case of an accident.

**Fragmented Risk Assessments**
Inconsistent safety standards and poorly defined hazard zones across maritime and land-based LNG operations exacerbate risks to both human populations and infrastructure. Jurisdictional overlaps and complexities, especially with locally implementing international standards, doesn‘t provide safety pathways which benefit local people and environments.

**Siting Risks**
Current practices for locating LNG facilities increase exposure to accidents, pollution, and environmental harm, particularly for communities and sensitive ecosystems. Fenceline communities are at the highest risk and the lack of community engagement in assessing these risks contributes to ongoing accidents and devastating consequences.

**Lack of Transparency**
Information gaps and limited data-sharing within the LNG industry obscure a full understanding of risks, impacts, and accident causes, reducing the effectiveness of safety interventions. This also applies to the development and updating of safety protocols, many of which are buried within industry and regulatory processes leading to difficulties for community based feedback and input.

**Safety Culture Deficiencies**
Organizational cost-cutting measures, including understaffing and insufficient training, lead to fatigue, errors, and increased risks of operational failures. With many safety and operational measures within the LNG industry relying on human intervention the lack of an industry wide culture of safety has contributed to many of the documented accidents.

**Climate Vulnerabilities**
LNG facilities are not adequately designed to withstand climate-related risks, and current protocols fail to address the full life-cycle impacts of methane emissions, impeding efforts toward sustainable energy practices. With a large proportion of LNG facilities being in coastal regions, which often bear the brunt of the climate crisis, the lack of climate related risk assessments and mitigation remains a common theme in industry related gap analyses.


**People fish near the Golden Pass LNG facility in Sabine Pass, Texas, which is adding liquefaction and export capabilities to allow flexible natural gas imports and exports. The facility is set to be operational in 2024.**

# 3. Introduction

**Liquefied fossil gas (LNG) is predominantly methane that has been cooled to become liquid, making it easier to store and transport, especially to places without pipelines. LNG infrastructure is energy-intensive, requiring power that may come from carbon intensive resources, and producing methane leaks through venting and refrigeration processes. Its lifecycle emissions, including flaring and shipping, make LNG even more energy-intensive than conventional fossil gas, contributing greatly to climate risks and hindering global climate change mitigation efforts (CHPNY et al. 2023).**

In addition to its disastrous climate impacts, LNG poses also substantial safety risks. It can create explosive vapor clouds, cause dangerous fires, and emit pollutants such as nitrogen oxides and volatile organic compounds, affecting nearby communities. Historical and recent accidents high-light these hazards. Despite the growing global and local opposition, some countries are expanding LNG infrastructure, increasing the potential for catastrophic accidents.

This report analyzes LNG accidents throughout the supply chain, evaluates the existing safety protocols or the absence of such protocols, and presents global case studies to illustrate the safety risks associated with LNG.

# 4. About LNG: A Flammable and Explosive Fuel

LNG is produced by cooling fossil gas to -162 °C (-260°F), which turns it into a liquid form. LNG is a cryogenic liquid[1] stored at its boiling temperature. When the pressure remains constant, the temperature can also stay stable. In its liquid form, LNG occupies less than 1/600th of the volume of fossil gas in its gaseous state (Figure 1). When exposed to normal atmospheric temperature, LNG will boil and release extremely cold gas. As a result, LNG is highly flammable and extremely cold, primarily composed of methane with a small percentage of other hydrocarbons. Even small amounts of LNG can expand to create large volumes of gas.

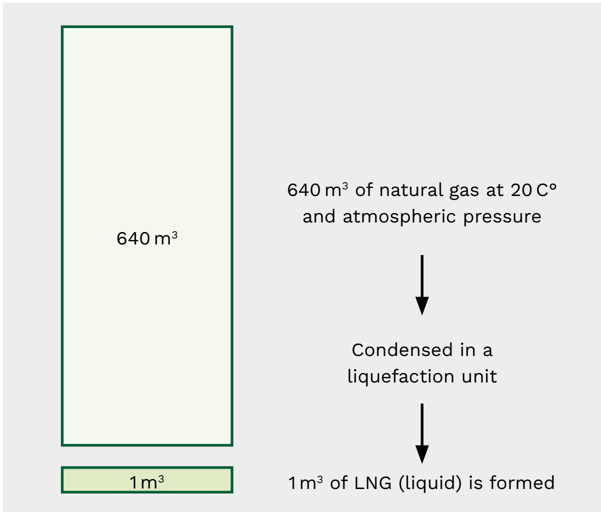



**Figure 1: Comparison of fossil gas and LNG volumes throughout the liquefaction process.**

## LNG is a Hazardous Chemical

LNG poses serious public safety hazards. LNG is colorless, odorless, and lighter than water. When LNG spills on the ground, it will boil and vaporize, forming rapidly expanding, odorless clouds that can flash-freeze skin and cause asphyxiation by displacing oxygen (CHPNY et al. 2023). LNG spilled on water at normal temperatures will boil vigorously and evaporate quickly. The vapor produced from boiling LNG is flammable and is considered a heavy gas. An LNG spill on water can lead to locally explosive boiling (NRT-RRT 2016).

When in vapor form, LNG becomes flammable when it mixes with air in a narrow concentration range of 5 % vapor to 15 % air by volume. Vapor from an evaporating LNG pool can ignite, forming what is known as a "Pool Fire", which can burn far hotter than other fuels and cannot be extinguished. If the vapor disperses and ignites at a downwind location it usually burns as a flash vapor fire. These fires radiate enough heat to cause second-degree burns on exposed skin from nearly a mile (1.6 km) away (CHPNY et al. 2023).

LNG is classified as a flammable and explosive hazardous chemical, presenting security risks across its production, processing, storage, transportation, and usage (Hongkai et al. 2019). LNG facilities also pose multiple health risks, including accidents, explosions, and both short- and long-term exposures to hazards like air pollution and noise.

## LNG Facilities: Ticking Time Bombs

LNG facilities are highly capital-intensive and include liquefaction plants, tanker ships and trucks, regasification terminals, and inland storage equipment (Figure 2). These facilities pose public health risks to nearby communities by releasing toxic air pollutants such as carbon monoxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds. Communities nearby LNG facilities are overburdened by pollution and environmental impacts (Heureaux-Torres, Chang, Donaghy 2024).

LNG facilities are susceptible to accidents including fires, leaks, and explosions. Facilities located near populated areas pose significant public safety risks. In June 2022, an explosion and fire caused by a vapor cloud at the Freeport LNG facility in Texas forced

1 Cryogenic liquids are gases at normal temperature and pressure but become liquid at very low temperatures. They are extremely cold liquids and, in the case of LNG, flammable when in contact with air

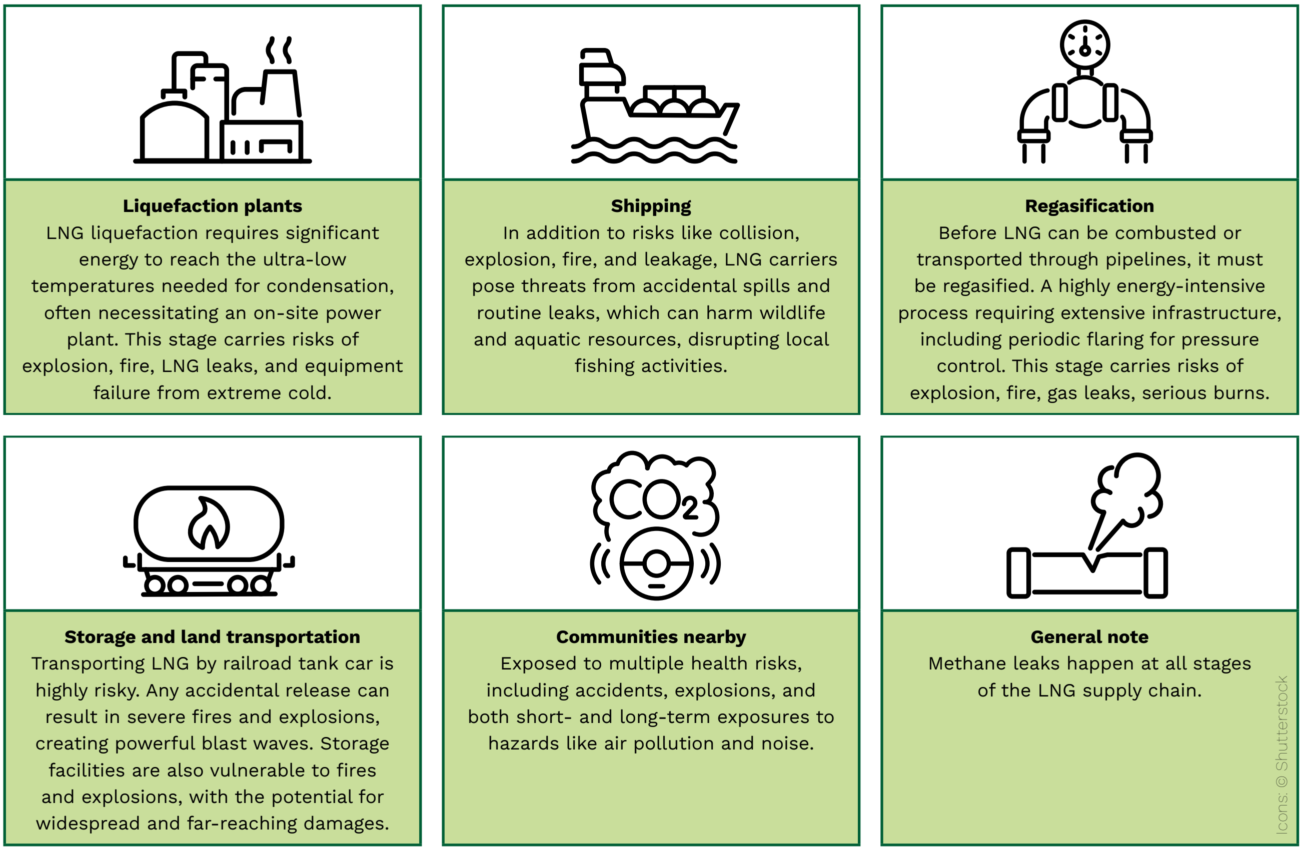



**Figure 2: Risks across the LNG Supply Chain.**

its shutdown for eight months. Although no facility workers were injured, the blast was powerful enough to knock nearby lifeguards from their chairs (CHPNY et al. 2023).

LNG facilities are also considered potential terrorist targets, with each LNG tanker shipment costing U. S. citizens around $40,000 – $80,000 for security (Parfomak 2003). This cost reflects measures overseen by federal agencies like the Coast Guard and the Department of Transportation's Office of Pipeline Safety, which coordinate with state and local authorities to safeguard LNG shipping and land-based facilities. While no LNG facility has been successfully attacked by terrorists, similar oil and gas infrastructure has been targeted globally, underscoring the perceived risks (Parfomak 2003). However, more recent data on security costs, along with an explanation of why these expenses fall to taxpayers instead of LNG companies, is needed to fully assess the financial burden and current funding approach for LNG facilities.

LNG facilities are primarily located in coastal areas, which are often inhabited by socio-economically vulnerable populations, and are already burdened by pollution and other ecological impacts (Saha et al. 2024). These facilities may also be situated in areas that hold ecological, socio-economic, and cultural significance (Earth Insight & SkyTruth 2024). LNG facilities are at heightened risk of accidents due to hurricanes, thunderstorms, and other storms that are expected to increase in intensity and frequency due to climate crisis, which is amplified by LNG life-cycle greenhouse gas (GHG) emissions (Tobar 2024). The locations and operations of LNG facilities pose significant risks to both people and the environment.

The combined energy demands of safety requirements including refrigeration, venting, leakage, flaring, and transport make LNG more energy-intensive than conventional fossil gas (Figure 3). A recent analysis suggests that large-scale LNG exports from the United States could increase global greenhouse gas emissions, driven both by the additional energy burden and the expansion of fossil fuels on the global market (Howarth 2024). Moreover, LNG tanks require evaporative cooling, which involves venting vaporized methane to maintain low temperatures and reduce explosion risks. Although some of this gas can be captured, for instance in larger LNG carrier vessels, leaks remain unavoidable.

# 5. LNG Accidents

Despite industry claims of an „exemplary safety record“ (Coote 2016), serious accidents have occurred throughout the LNG supply chain and will continue to occur. Any stage in the process can lead to severe accidents, potentially resulting in significant numbers of fatalities and injuries, and extensive material and environmental damages.

The first major reported accident in the history of the LNG industry was in 1944 when a fire and explosion occurred at an LNG gas storage station in Cleveland, USA (City of Hyattsville 2005). This tragic event resulted in 130 deaths, including 98 workers. Additionally, 32 individuals were reported missing, and 251 sustained serious injuries requiring hospitalization, while 150 others received treatment at local stations. More than 10,000 people had to be evacuated from the area. Despite decades of industry development, accidents continue to occur.

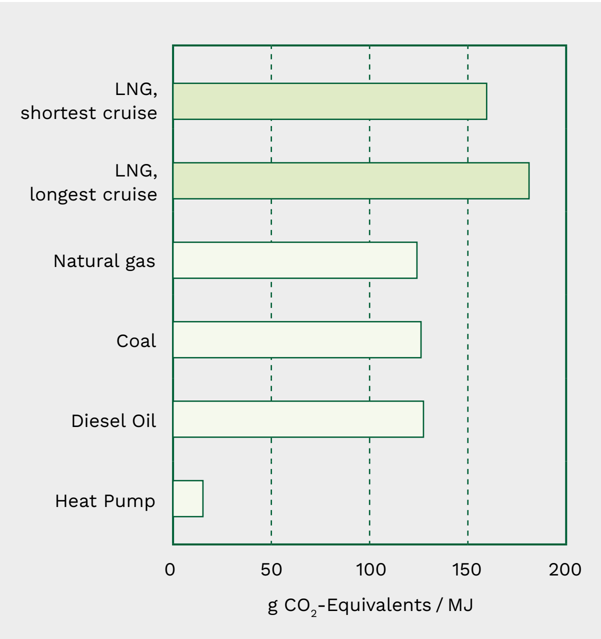



**Figure 3: Full lifecycle greenhouse gas footprint for LNG for both short and long cruises compared with the use in the US of coal, diesel oil, fossil gas, and electric-power ground-source heat pump powered by the average European electric grid.**

Liquified fossil gas is easy to leak, with volatile diffusion, flammability, and explosion (Li et al. 2021). Accordingly, accidents can result in significant casualties, property damage, and environmental harm. The full extent of safety risks and warnings from the LNG industry has not been adequately acknowledged, as evidenced by the continued frequency of accidents despite safety measures (Appendix). The industry has been building LNG infrastructure without fully accounting for the risk of a major accident. This oversight leaves populations vulnerable, with potential consequences that could be catastrophic—a concern explored in detail throughout this paper.

The objective of this analysis is to identify LNG accidents that have occurred globally and throughout the LNG supply chain. The analysis in this report aims to provide a first step towards a comprehensive assessment of the accidents associated with the LNG industry.

## Analysis Limitations

This study has a global scope and was conducted exclusively in English during the research phase. As a result, local accidents and protocols may have been missed due to language limitations or the absence of localized information in the database used. Such information might otherwise have been available through sources like local media. While the risk of LNG tank explosions in human-related applications is increasingly recognized (Hongkai Liu et al. 2019), this analysis excluded accidents and protocols involving direct LNG use, such as in power plants, trucks, or fuel applications. Similarly, fossil gas facilities were also excluded from this study. However, subsea pipelines were included, assuming they could be part of the LNG facility or supply chain. This analysis does not cover the accidents and risks linked to the construction of LNG facilities which has been associated with environmental, social, and economic impacts, including the destruction of marine habitats, rising housing prices, and increased cost of living (van der Vegt 2018).

# LNG Industry Accidents

A total of 104 accidents linked to the LNG industry facilities that occurred between 1944 and 2024 were retrieved and analyzed. Accidents were grouped by facilities (Appendix).

## Accident Types

The U. S. Department of Transportation identifies three primary hazards associated with LNG: flammability (risk of fire or explosion from leaks), toxicity (risk of asphyxiation due to exposure to non-odorized gas), and cryogenic danger (risk of injury or equipment failure from extreme cold) (Murphy et al. 1995). In this analysis, accident types were categorized into explosion, fire, marine incidents, and collision / rollover to offer a more comprehensive understanding of the scope of accident types. LNG accidents can span multiple categories; for example, an explosion and fire might occur simultaneously during a collision / rollover or an LNG leakage can take place prior to a fire or explosion.

Among the 104 LNG industry-related accidents analyzed, LNG leaks were the most frequent, accounting for 22 %, followed closely by fires at 20 %. Marine incidents and explosions ranked third and fourth, comprising 19 % and 16 % of the total, respectively. Collisions / rollovers represented 7 % of the incidents, while a combination of undisclosed and other types of accidents made up the remaining 14 %.

### Explosion

- Physical (pressure related) Explosion:
  LNG tanks contain both gas and liquid phases, and during storage, the movement of LNG—whether added or removed—can create phenomena such as vortexes, geysers, or water hammer effects. If excess vapor is not released in time, the pressure inside the tank can increase beyond its design limit, potentially causing a physical explosion due to overpressure (Liu et al. 2019). For example, in 2007, an explosion during a tank pressure test in Shanghai, China, resulted in one fatality and left 16 people injured (Liu et al. 2019).
- Chemical Explosion:
  Chemical explosions in LNG tank areas primarily involve two scenarios: a vapor cloud explosion (VCE) and a boiling liquid expanding vapor explosion (BLEVE). A VCE occurs when LNG leaks and mixes with air, creating a flammable vapor cloud that ignites upon contact with a spark or flame in a confined space. A BLEVE, on the other hand, happens when a storage tank is exposed to fire, impact, or mechanical failure. If the tank cracks under these conditions, a large amount of liquefied gas may escape. If a fire is present or overpressure occurs within the tank, a BLEVE can result in a violent explosion (Liu et al. 2019). Notable examples include the 1987 LNG vapor cloud explosion at the Nevada test site in the US and the 2004 LNG refinery vapor cloud explosion in Algeria.

### Fire

When LNG leaks, the gas quickly turns into methane vapor and mixes with air, forming a vapor cloud. If the concentration of this vapor reaches its explosive limit (5 % to 15 %), it can ignite upon contact with a fire source. A lower concentration may result in a flash fire, while a higher concentration can lead to sustained combustion, creating a pool fire as the vapor burns on the surface of the LNG liquid. If the vapor ignites directly, it causes a spray fire (Liu et al. 2019). Exposure to the intense heat of an LNG fire for just 30 seconds can cause severe burns up to a mile away (U.S. Government Accountability Office, 2007). For example, in 1985, a fire broke out at an LNG receiving station in Alabama, U. S., when a vapor cloud entered the control room and ignited. Similarly, in 1989, a flash fire at a British LNG peak shaving station spread 40 meters after a vapor cloud ignited.

### LNG Leakage

LNG poses safety risks due to its low explosion limits (5 % to 15 %). If the valves, pipes, or containers in storage and transportation systems are damaged or not properly sealed, LNG can leak and quickly mix with air, reaching explosive concentrations due to its heavy gas properties (Liu et al. 2019). In the presence of open flames or sparks, this can result in violent explosions and fires, posing severe hazards to life and properties. Additionally, LNG leaks can cause frostbite from low temperatures and other secondary hazards, including toxicity risks from asphyxiation due to exposure to non-odorized gas. For instance, in 1971, approximately 2,000 tons of LNG leaked at the La Spezia import terminal in Italy (City of

Hyattsville 2005). Similarly, in 1993, 150 tons of LNG were released at a peak shaving station in the United Kingdom (Liu et al. 2019).

**Marine Incidents**

LNG marine operations pose significant risks to public safety and the environment. Incidents involving LNG carrier vessels can stem from various factors: technical failures like engine, propulsion, and steering malfunctions; operational errors tied to human factors such as poor vessel control, navigation mistakes, and inadequate maintenance; environmental challenges, especially severe weather; and security threats, including piracy, which endanger both crew and public safety. Risks associated with non-technical and non-operational factors may also escalate as climate change intensifies extreme weather patterns and geopolitical tensions increase.

The LNG trade by sea began in 1964 with shipments from Algeria to England and France (Schneider 1977). Marine incidents not only risk physical harm but also carry the potential for spills and environmental pollution. On October 6, 2015, the LNG carrier Al Oraiq collided with the cargo vessel Flinterstar near Zeebrugge in a high-traffic area of the North Sea (Cedre 2024). While Al Oraiq managed to reach port for inspection, Flinterstar was severely damaged, grounded, and sank on a nearby sandbank. The vessel held 3,000 tonnes of steel and 545 tonnes of fuel, prompting Belgium to activate its national contingency plan, establish an exclusion zone, and conduct environmental monitoring (Cedre 2024). This incident highlights the considerable risks LNG marine transport poses to crews, coastal communities, and the marine ecosystem.

Ports play an important role as the interface between the land and maritime operations of the LNG industry. As of 2020, approximately 41 LNG port terminals operate worldwide, yet knowledge about and standardized practices for safe LNG storage, handling, and supply is still lacking (Aneziris et al. 2020). Specifically, gaps in harmonizing LNG safety standards across maritime and land-based port operations pose a risk. Current safety frameworks would benefit from improved quantitative risk assessments, which could better define safety and hazard zones around LNG storage and bunkering activities (Aneziris et al. 2020). Consistent safety practices and regulations across nations are essential to bolstering LNG port safety.

**Collision / Rollover**

The transportation of LNG by tank trucks presents significant risks, especially in densely populated areas, such as near port facilities where LNG land and sea operations intersect. LNG truck accidents often involve collisions and rollovers, and are commonly caused by blowouts, driver fatigue, collisions, rollovers, and handling errors, such as failing to avoid pedestrians or struggling to navigate turns.

In 1998, a TransGas LNG tank truck in Massachusetts, U. S., was sideswiped at high speed, causing it to crash into a guardrail and rupture its diesel fuel tank (City of Hyattsville 2005). The resulting fire tragically trapped the driver in the cab. In another devastating incident on June 13, 2020, in Zhejiang, China, a tanker truck carrying liquefied gas exploded on a highway near Liangshan Village, killing 19 people and injuring over 170 (BBC 2020). The explosion sent debris and plumes of smoke across the area, causing extensive damage to nearby buildings.
A second explosion occurred when the damaged truck was propelled onto a nearby factory building. More than 2,600 rescue workers were deployed, and authorities launched an investigation. The truck's owner had been penalized multiple times for health and safety violations in the past.Another close call for a disaster was a collision between two ships in Australia in July just this year, which resulted in serious damage to an empty LNG tank and highlighted yet again the risks associated with LNG transport (Wingrove 2024).

**Aftermath of a tanker explosion near Wenling, China in 2020, which killed 19 people.**

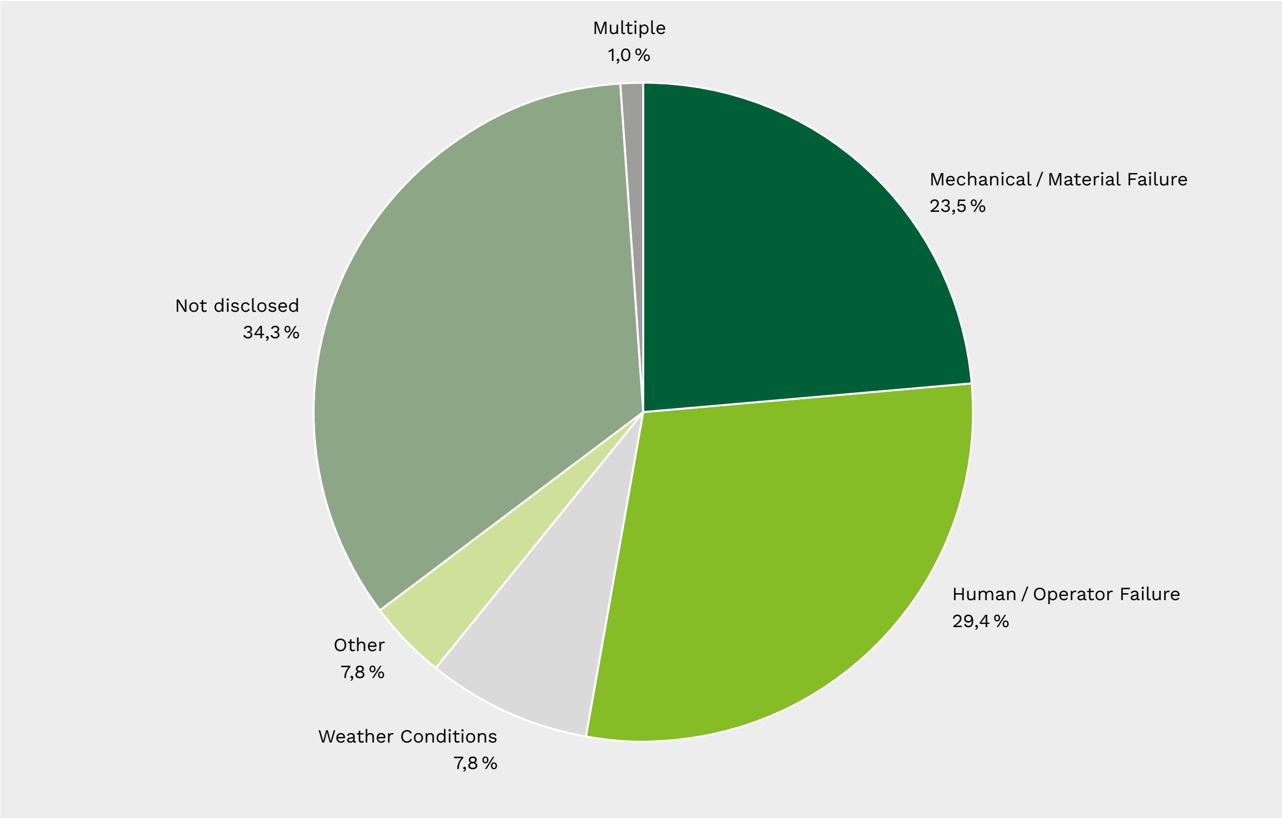



**Figure 4: Chart of LNG accidents causes based on 104 accidents retrieved. Facilities may have multiple accident types. Further details and examples of causes of accidents are described in the following sections.**

Transporting LNG by rail presents significant safety risks, as highlighted by numerous safety and public advocacy organizations (Rao 2023). Catastrophic fires, explosions, and inadequate safety measures have been associated with transporting LNG by rail. LNG spills can rapidly form flammable vapor clouds, and incidents involving multiple rail cars could overwhelm local emergency response capabilities, posing risks to both responders and communities. Studies have noted the potential for BLEVEs, cascading failures, and long-term environmental hazards. Despite new regulations introduced in 2020 requiring operational safeguards, many experts argue that these measures are insufficient to address the risks (CHPNY et al. 2023). Criticisms also extend to inadequate training and resources for emergency responders, leaving communities along transport routes particularly vulnerable.

## Accident Causes

Accidents in the LNG industry mainly result from mechanical/material failure, human/operator error, weather, and natural conditions, and other causes.

As shown in Figure 4, human/operator errors, along with mechanical/material failures, account for 53 % of all LNG industry accidents. Additionally, 34 % of the 104 accidents analyzed did not disclose their causes, highlighting the significant lack of transparency (see Accidents Analysis: Reporting and Transparency Challenges below). Even if LNG facilities were managed according to established guidelines, they still pose risks to nearby residents and the environment through leaks, explosions, and other accidents.

### Mechanical / Material Failure

Mechanical/material failures have caused numerous accidents in LNG facilities, with primary issues linked to poor equipment calibration, material fatigue, wear and tear, unsuitable materials, extreme temperatures, and inadequate maintenance.

### Human / Operator Error

LNG accidents associated with human factors include faulty equipment, operational mistakes, inadequate maintenance or monitoring, insufficient training, and underinvestment. Cost-cutting strategies at LNG facilities can result in understaffing, procedural errors, and employee fatigue all of which increase the risk of accidents (IFO Group 2022). One example is the 2022 vapor cloud explosion at the Freeport LNG facility in Texas, US. The explosion was triggered when flammable methane vapor came into contact with damaged electrical conduits, causing a vapor cloud explosion and a small secondary fire. Investigators found that a blocked relief valve had caused overpressure in an 18-inch recirculation line. This relief valve had not been reopened after maintenance, leading to a build-up of pressure in the pipe. Procedural lapses, such as deficiencies in valve testing, insufficient alarm settings for rising temperatures, and operating procedures allowing operators to close valves that risked isolating LNG in the pipeline, contributed to the incident. The report also identified that the control room's monitoring was insufficient, as critical alarms were constantly sounding on equipment out of service for years, leading to „alarm fatigue" among operators. Severely damaged electrical wiring likely ignited the escaping gas, resulting in the fireball that followed the pipeline breach. The facility had over 100 air permit violations prior to this incident, which went largely unenforced until the state imposed a nominal fine of $9,000 (Saha et al. 2024).

#### Weather and Natural Conditions

Natural hazards—including extreme weather and seismic activity—pose significant risks to LNG facilities and operations. Weather, in particular, plays a crucial role in LNG safety, as most LNG trade relies on maritime transport. For instance, as the world's largest LNG exporter, the United States ships over 99.9 % of its LNG exports by sea (Carr et al. 2024), underscoring the importance of weather conditions for the safety of LNG transport, crews, facilities, and nearby communities.

A review of maritime accidents linked to weather and natural conditions reveals several critical incidents (Appendix). For example, In 1964 and 1965, it was reported that while loading the Methane Princess LNG carrier, lightning strikes ignited routine vapor venting. During Typhoon Maemi in 2003, two LNG carrier vessels under construction—the Fuwairit and Galicia Spirit—were grounded, and the mooring ropes of the Berge Arzew LNG carrier snapped. While the Galicia Spirit sustained damage to its bottom and starboard shell plating, no casualties were reported related to these incidents.

## Accidents Analysis: Reporting and Transparency Challenges

The analysis of accidents within the LNG industry highlights major shortcomings in information availability, transparency, detail, and consistency across reporting sources. The following sections outline the primary issues identified, each of which limits a comprehensive understanding of accident causes, impacts, and preventive measures.

#### Omission of Information

A significant amount of crucial information is omitted in the reporting of LNG accidents, which complicates efforts to understand the underlying causes and accountability. Key findings include:

- Inadequate Causal Details: Many accident reports lack specific information about the causes. This omission is more prominent among maritime accidents. Without clear cause analysis, it becomes challenging to address accountability.
- Missing Protocol Violations: Reports often fail to specify which operational or safety protocols, if any, were violated during an incident. This omission prevents the understanding of procedural failures and effectiveness (or lack of) of safety protocols.
- Undisclosed Financial Loss: For the majority of accidents, details on financial losses remain unspecified. This lack of transparency impedes accurate assessment of the economic impact of accidents for the LNG industry, related sectors, and the public.

#### Lack of Details

The scarcity of detailed reporting also limits insights into the consequences and broader impacts of accidents:

- Delayed and Insufficient Information: In some cases, information is delayed or lacking in critical detail. For example, a 2018 investigation into a leakage accident at Cheniere Energy's Sabine Pass export facility revealed that a Pipeline and Hazardous Materials Safety Administration (PHMSA) investigator struggled to obtain timely

and sufficiently detailed information from the company (CHPNY et al. 2023).
- Omission of Facility Names and Location: Many sources omit the names of facilities involved in incidents, reducing the transparency needed to track recurring issues across specific sites and hindering efforts to identify facilities with repeated safety problems. The location of the accident was also omitted for most of the maritime accidents, making it difficult to access what marine areas are most vulnerable to LNG accidents.
- Limited Data on Material and Environmental Impact: Information regarding material damage and environmental impacts is often minimal, making it difficult to assess the full scope of an accident's consequences. This gap in reporting prevents a comprehensive understanding of the environmental risks posed by the LNG industry.

The pervasive gaps in information and transparency reflect a need for stricter reporting standards and improved data-sharing practices across the LNG industry to facilitate a more thorough analysis of accident causes, impacts, and prevention methods.

The analysis in this report may significantly underestimate the true scope of LNG-related incidents due to intentional or unintentional underreporting. For example, during a 1971 marine incident involving an LNG leak on the Descartes LNG Tank, the crew reportedly attempted to conceal the leak from authorities (ERM 2018), highlighting systemic challenges in transparency and accountability within the industry.

It has been documented that risk analysis in the LNG sector lacks a strong focus on improved data quality, real-time data integration, and the shift from traditional to dynamic risk assessment methods. Advanced risk assessment tools and techniques are also essential to address these gaps. Presently, „expert judgment" remains the primary method used in LNG industry risk analyses, underscoring a shortage of reliable, high-quality data necessary for comprehensive evaluations (Animah & Shafiee 2020). Additionally, many studies in this field are funded directly or indirectly by the LNG industry, which can lead to potential biases and limit the scope of findings, often downplaying significant risks that require attention.

Furthermore, the LNG industry likely greatly underestimated incidents of vapor cloud explosions (VCE) at LNG facilities. The actual impact of these incidents could be 15 to 20 times greater than the industry's current projections (Englund 2021). Even after 75 years in operation, the LNG industry still lacked proper processes as of 2019 to reliably assess whether its software models accurately calculated LNG-related hazards (Mandel 2019).

## LNG Accidents Conclusion

These accidents highlight the catastrophic risks associated with the LNG industry. The handling including liquefaction and regasification, transportation, and storage of LNG pose significant challenges, particularly for communities located near LNG facilities, workers and ports. Conflicting information, underreporting of incidents, and a lack of transparency regarding the circumstances surrounding accidents obscure the true extent of the harm caused by the LNG industry and its potential for catastrophic disasters. The information gap hinders the ability to evaluate and create emergency plans and responses during accidents, rendering LNG safety systems unreliable.

LNG spill dynamics and hazards, including vapor production, dispersion, and combustion, remain poorly understood and require further research. Key risks to human safety include pool fires, jet fires, and vapor cloud explosions, with LNG facilities also considered potential terrorist targets. LNG hazards are not well understood enough to fully support terminal approvals, and further safety research is needed to address risks such as flammable vapor clouds and potential attacks.

# 6. LNG Safety Protocols

**International safety standards for LNG shipping, bunkering, port and facility management have been developed by international and regional bodies, and revised over the years, in an attempt to reduce accidents, fatalities, and near misses. However, these protocols have had varying degrees of success with accidents continuing to happen and people continuing to be injured and tragically, dying. Even in the highly regulated European environment, this is the case (eg. 2015 LNG carrier Al Oraiq collision – Annex A).**

Table A2 of Appendix outlines the timeline of safety protocols for both land and sea operation. Despite the establishment and updates of these protocols, LNG accidents persist. The timeline of historical LNG accidents, combined with the evolution of safety protocols for both land and sea operations, reveals a misalignment between the frequency and severity of accidents and the establishment or updating of safety protocols. Over the past 80 years, the frequency of protocol updates have only occurred within the last three years. Despite these recent efforts, accidents continue to occur, underscoring persistent gaps in safety measures.

For the context of this research, several key international codes, measures, guidelines and conventions, specific to LNG, were considered that mandate and guide operations globally and regionally. Overarching safety protocols have been put in place, such as the International Maritime Organization (IMO)'s Safety of Life at Sea (SOLAS) and Prevention of Pollution from Ships (MARPOL) conventions, which aren't specific to LNG operations and won't be included in this report.

Many countries rely on international standards with supplemental local and national regulations to govern LNG operations and shipping. India, Japan, Canada, US, EU, UK, and to a lesser degree China (GIIGNL 2019), tend to go further than just supplemental regulations and have adopted more robust standards for their jurisdictions. Highlights of the regional standards are listed in the next section. However, without exception, these regional approaches heavily reference and embed key international standards such as the International Standards Organization, (ISO), IMO, and National Fire Protection Association (NFPA). With the IMO process for updating and revising their codes and guidelines restricted to IMO members and not designed for public engagement, and ISO standards even further buried behind industry processes and out of public sight, it is easy to understand how there is limited involvement of community members and ultimately those most affected by catastrophic incidents and accidents. If the myriad rules and regulations were working to prevent deaths and environmental damage it might be excusable for such an opaque process, but that's clearly not the case.

The fact that this report is one of a kind in attempting to summarize LNG industry accidents and gaps and their safety procedures and protocols while giving a human, and non-industry dimension to the sector's unsafe practices is telling.

Desktop comparative research across global and regional LNG safety governance frameworks points to common themes as to why LNG operations continue to present safety concerns and risks to communities and individual lives (Aneziris et al. 2020; Carr et al. 2023; Ha et al. 2019). At a general and high level, major themes, gaps, shortcomings, and areas for improvement include:

**Locating Facilities and Bunkering**
Few ports have adequately implemented risk-based safety zones around (Koo et al. 2009) LNG storage and bunkering areas (Aneziris et al. 2020), leading to potential safety gaps in densely populated or heavily trafficked areas. Often the broader environmental and community impacts of LNG operations, particularly in areas where ships operate near populated coastal regions are absent in planning, management and environmental impact assessments (Aneziris 2019; Raj and Lemoff 2009).

**Methane Slip**
LNG shipping and bunkering rules (Atzampos 2024; IACS 2016) do not comprehensively address the detection or mitigation of methane slip, allowing for

**A pipeline explosion in Deer Park, Texas in 2024 sent massive flames into the air, forcing evacuations and road closures.**

gas leakage throughout the supply chain, increasing risks and climate impacts. Gas rapidly vaporizes when it leaks, creating a flammable gas cloud risking fires and explosions.

### Emergency Planning

Detailed guidance on comprehensive emergency preparedness plans (World Bank Group 2009), particularly regarding coordination with shore-based emergency responders (The Danish Maritime Authority 2012) is missing (Government of Canada 2024) and or thin on details within codes and protocols (Blanchat et al. 2014).

### Training

There is inadequate training (Gerbec and Aneziri 2020) and competency standards for LNG handling personnel, which increases human error during bunkering and storage operations (Bohacikova 2024). An inadequate safety culture was often cited as contributing to accidents and deaths (CHPNY 2023; Cherigui 2022). Many safety protocols rely on human interventions, such as manual stopping of operations or recognizing critical situations during abnormal events, which poses a risk of human error, especially under high-stress conditions.

### Testing of Equipment and Systems

Comprehensive requirements are lacking for regular testing and validation of critical systems, such as cargo containment, leak detection (Lieb 2001), and gas processing systems. Periodic testing and certification for critical equipment, such as containment systems and gas detection sensors, would help prevent system failures and leaks during operations (EU 2018).

**Jurisdictional Coordination**
Harmonizing operations across states and continents continues to be a challenge given the spider web of regulations, guidelines and standards (EU 2018). Translating international codes to local circumstances still alludes individual facilities, leading to catastrophic results (Cherigui 2022).

**Transparency**
It is extremely difficult for community engagement in processes that are proprietary, obtuse and behind paywalls. Considering the number of accidents and deaths, industry centric approaches to operations, governance and safety need to profoundly change.

It should be noted that the lack of transparency with many LNG safety protocols, often not being available in the public domain, speaks to the general lack of civil society and community engagement in scrutinizing these various procedures. The most glaring example is the proprietary nature of the International Standards Association (ISO) standards, with the texts behind paywalls. These key, difficult to access, documents form the basis of much of the industry's guidelines but they remain out of public circulation for researchers and concerned individuals wanting to hold the industry to account. The authors of this report have relied on publicly available summaries and expert opinions to inform conclusions about these specific LNG safety protocols.

## International and Prominent Regional Guidelines

**International Guidelines**
- The IMO International Gas Carrier Code (IGC) (IGC Code 2016), International Code of Safety for Ships using Gases or other Low flashpoint Fuels (IGF) (IGF Cde 2024) and the related International Association of Classification Societies (IACS) Rec 142, all form the foundation for regulations for the transport of LNG by ship, by providing design, operations, risk assessment and construction guidelines for carriage, use as fuel, and bunkering.

**International Safety Standards (ISO)**
- 28460:2010 – specifies the requirements for ship, terminal and port service providers to ensure the safe transit of an LNG carrier through the port area and the safe and efficient transfer of its cargo.
- 16903:2015 – gives guidance on the characteristics of LNG and the cryogenic materials used in the LNG industry. It also gives guidance on health and safety matters and is intended to act as a reference document for the implementation of other standards in the LNG field.
- 20159:2021 – specification for bunkering of LNG fuelled vessels.
- 16901:2022 – guidance on performing risk assessment in the design of onshore LNG installations including the ship / shore interface.

- The National Fire Protection Association's NFPA 59A includes standards for the production, storage, and handling of LNG and addresses the design, construction, and operation of facilities involved in the liquefaction, storage, and handling of LNG. This standard covers issues such as site selection, fire protection, spill control, and emergency response.

- The World Bank has published environmental, health, and safety technical reference documents with general and industry- specific examples of Good International Industry Practice (GIIP).

- International Electrotechnical Commission (IEC) 60079 is a set of standards for equipment used in explosive atmospheres, including electrical installations in LNG facilities where flammable gases could be present. These standards focus on preventing electrical sparks or failures that could lead to fires or explosions.

- International Group of Liquefied fossil gas Importers (GIIGNL) promotes the LNG industry and summarizes codes and regulations, such as in their information papers #3 (LNG ships) and #4 (managing LNG risks).

- Society for Gas as Marine Fuel (SGMF) promotes safety and best practices for LNG as a marine fuel, producing guiding documents (often password / paywall protected) such as their bunkering safety guidelines (SGMF 2024).

- The Society of International Gas Tanker and Terminal Operators (SIGTTO) publishes (some behind a paywall) a variety of guidance documents (SIGTTO 2024), including a recent Review of Practice for Gas as Fuel on Gas Carriers which uses a risk-based approach to review the hazards from existing control measures in the IGC Code, standards, and industry best practice.

- The International Energy Agency (IEA) does not directly set safety protocols for LNG facilities, it collaborates with international organizations, energy companies, and governments to advocate for safety and best practices across the energy sector, including LNG.

## Prominent Regional Guidelines

**European Union**

- The Seveso-III Directive (or Directive 2012/18/EU) requires companies operating LNG facilities to take preventive measures and have emergency plans in place for responding to accidents.
- European Maritime Safety Agency (EMSA) provides guidance on LNG Bunkering to Port Authorities / Administrations ( (EMSA) 2018).
- EN 1473 is a European standard that provides guidelines for the design, construction, and operation of onshore LNG installations (CEN 2021).

**United States**

- American Petroleum Institute (API) maintains hundreds of standards (API 2021) covering all segments of the Oil and Gas industry. API 620 is one standard the LNG industry frequently uses for guidance on storage tanks.
- US Occupational Safety and Health Administration (OSHA) has standard 1910.110 for the storage and handling of LNG (OSHS 2007).
- US Coast Guard and US Homeland Security support the Liquefied Gas Carrier (LGC) National Center of Expertise (NCOE) ((LGCNCOE 2009) which provides oversight, codes, policy letters, alerts, inspection notices, guidance and a regulatory framework for liquefied gas carriers, liquefied gas as fuel, liquefied gas bunkering, and liquified gas facilities.
- LNG facilities (Danish Maritime Authority 2012) are regulated by several federal US agencies, primarily the Federal Energy Regulatory Commission (FERC), the U.S. Coast Guard (USCG), the Pipeline and Hazardous Materials Safety Administration (PHMSA), and by state utility regulatory agencies. Import and export terminals are inspected for safe operations by the FERC, USCG, and PHMSA.
- Canadian Standards Association (CSA group) which is accredited by the Standards Council of Canada, has developed more than 3,000 standards, codes and related products for the safety, design or performance of a wide range of products and services. CSA Z276:22 and CSA SPE-276.1:20 include guidelines for the ‚entire lifecycle of LNG facilities‘, from construction to operation and decommissioning, the management of LNG facilities and requirements for the design and construction of LNG tanks, pipelines, and other equipment used in storing and handling liquefied fossil gas.

**Asia**

- The Japan Gas Association (JGA) consists of city gas utilities providing recommended practices which are also used by other Asian countries. Relevant recommendations for LNG include: LNG In-ground Storage (JGA-107-RPIS,2012); LNG Aboveground Storage (JGA-108-RPAS,2012); LNG Facilities (JGA-102,2015 ); Safety and Security in Gas Production Facilities (JGA-103,2017).
- India has developed a high-level code, OISD2 Standard 194, for the storage and handling of LNG. This standard is largely based on the US NFPA 59A standard, while also incorporating elements from other OISD standards. Additionally, it draws from European standards like EN1473, British standards, and API 620 (GIIGNL 2019).

# 7. Case Studies

## The Skikda LNG Plant Explosion

In one of the deadliest accidents in the LNG industry, in 2004 the Skikda LNG plant in Algeria suffered a catastrophic incident that claimed 27 lives, including operators, maintenance workers, safety personnel, and security staff. An additional 56 to 72 people were injured. The tragedy began with an explosion in a steam boiler, part of the LNG production plant, which subsequently triggered a massive vapor-cloud explosion and fire that burned for eight hours before being extinguished. Initial findings suggest that an undetermined hydrocarbon leak in a semi-confined area between unit 40's control room, the boiler, and the liquefaction area may have been the source of the explosion. However, due to the nature of the incident, the exact origin of the leak may remain unknown. Notably, the control room's proximity to administrative, maintenance, and security buildings contributed significantly to the high number of injuries and fatalities.

Reasons for the Skikda disaster have been well documented, pointing to poor maintenance, inadequate emergency preparedness, siting design failures, breakdowns in communication, and a poor general safety culture (Ouddai et al., 2012). Unfortunately these reasons aren't isolated to this accident nor this time period (see safety summary). As recently as 2022, research on the LNG ship-port interface at Algerian LNG facilities found that there was an urgent need for a new approach that integrates leadership and safety commitments, proactive communication, effective personnel training, and continuous improvement to strengthen safety (Cherigui 2022). Many of the same deficiencies and worrying safety protocols and measures identified in association with the 2004 plant explosion still persist today. Algeria relies heavily on international standards, such as ISO, IMO, SIGTTO, in its regulations and legislation. The shortcomings in these international protocols have global implications, despite recent updates this year.

## LNG Carrier Vessels Incidents in the European Union

Europe has one of the most comprehensive safety regimes for LNG operations, facilities and shipping. International standards are augmented with European Maritime Safety Agency (EMSA) guidance, the EU specific Seveso Directive, and detailed EU standards such as EN 1473 for the design, construction, and operation of onshore liquefied fossil gas (LNG) installations. These multiple layers of regulation however haven't stopped accidents from occuring, including related to shipping in EU waters

Many marine shipping accidents at sea have very little publicly available data, which is problematic for location specific analysis. The known unknowns in this space are significant. According to Wood et al. (2019), the majority of EU LNG-related near misses and accidents have occurred within port environments, highlighting the critical need for robust port safety measures and real-time data.

Some noteworthy incidents within the EU include:

- 2002: The LNG carrier Norman Lady collided with a U. S. military nuclear vessel east of the Strait of Gibraltar. This collision led to seawater leakage into the LNG ship's double bottom dry tank.
- 2010: At the French Montoir de Bretagne terminal, a discharge operation malfunction resulted in liquid entering the gas take-off line, which damaged the ship's manifold and feed lines.
- 2015: The LNG carrier Al Oraiq collided with the cargo vessel Flinterstar near Zeebrugge, Belgium. The collision caused minor damage and a water intake on the LNG carrier, but the Flinterstar grounded and sank on a shallow sandbank 5.3 nautical miles off the coast. It carried 3,000 tonnes of steel and held approximately 430 tonnes of heavy fuel oil and 115 tonnes of diesel, posing an environmental hazard in EU waters.

## Staten Island LNG Accident

In 1973, a tragic accident at an LNG facility on Staten Island, USA, caused the deaths of 40 construction workers, and three others sustained injuries due to asphyxiation. The incident occurred while workers were inside an empty storage tank, conducting repairs. During the repairs, a fire broke out, causing a rapid pressure increase that lifted the tank's concrete dome, which then collapsed back down into the tank. The fire is thought to have ignited polyurethane insulation inside the tank, with pockets of trapped methane gas contributing to the explosion. These gas pockets likely lingered from a previous LNG leak into the insulation after a breach in the tank's liner.

Although industry asserts that safety precautions have been implemented at all LNG facilities built and operated since the Cleveland accident in 1944, this similar Staten Island incident occurred 29 years later. The Staten Island disaster is frequently cited by the LNG industry as a construction accident, however many disagree, pointing to the latent vapors from the heavier components of stored LNG making it an LNG-related incident. As with the EU, the US has layered its own safety and regulatory protocols on top of international standards (see summary of guidelines). When looking at the entirety of US protocols and accidents, several conclusions can still be drawn where improvements need to be made (Siu et al. 1999), aligned with global shortcomings: inadequate hazard detection systems, limited emergency response training, maintenance gaps, and communication and coordination issues (see earlier in the report).

## Atlantic Canada LNG Facility – Trinidad and Tobago

The Atlantic Canada LNG facility in Trinidad and Tobago has experienced multiple incidents over the years, with safety concerns spanning over two decades. In 2001, two workers tragically fell to their deaths from scaffolding while working on a 5.6 million cubic-foot-capacity tank. In 2006, an employee was injured when a temporary isolation plug on an eight-inch pipeline was blown by pressure buildup at the facility‘s Train 2 unit. That same year, Train 2 was also temporarily shut down due to a gas leak from a two-inch pipeline. More recently, in 2017, the entire facility had to be evacuated following a fire in one of its power generation units. In 2024, another evacuation took place after a leak was detected in one of the plant‘s tanks.

Information is sparse but it appears that Trinidad and Tobago does not add, implement, or enforce safety rules which go above international standards. This reality highlights the importance of up to date and needed reform to standards such as ISO and IMO. With the lack of transparency and limited community involvement and engagement in the design and updating of international rules, it's difficult to imagine how tailored and relevant they will continue to be for domestic LNG operations. The Trinidad and Tobago Gas Master Plan (2015) points to safety protocols related to:

- EU Seveso III Directive (Directive 2012/18/EC) and EN 1473 for LNG storage
- European ADR (Agreement concerning the International Carriage of Dangerous Goods by Road) focusing on safety compliance, checks, and design standards
- SO 20421-2 and EN 13530-2 standards for large cryogenic transportable vessels alongside
- ISO standards (16901, 18683, and 20519) for Ship-to-Shore interface providing guidelines on risk assessment, bunkering systems, and safety zones around bunkering areas, essential for LNG transfer between ship and shore
- ISO and IMO standards for LNG bunkering operations.

# 8. Conclusion

It is clear that LNG has no place in a fully renewable energy system which is required to cut emissions drastically in a short time. The overwhelming human and environmental costs coupled with the historical frequency of LNG accidents highlight the need for transformative change in LNG industry practices, government regulations, and safety protocols. Given this reality, key recommendations can be drawn based on the research in this report aiming to critically address LNG operations:

**1. Pause Operations and Cancel Planned Projects**
Given the considerable uncertainties surrounding LNG safety and the substantial risks it poses to the public, states must pause operations and reassess the safety measures of operational projects. Additionally, planned projects must be cancelled to avoid further emissions, accidents, deaths, injuries, and environmental damage.

**2. Improved Transparency**
The LNG industry must be held accountable for closing existing information and transparency gaps by establishing rigorous reporting standards and robust data-sharing practices. This would expose the full scope of industry impacts and harms, allowing for an in-depth analysis of accident causes and consequences, and ensuring that both risks and preventive measures are fully understood and addressed before existing facilities are phased out. Transparent reporting would also lay the groundwork for phasing out LNG in favor of safer, renewable alternatives.

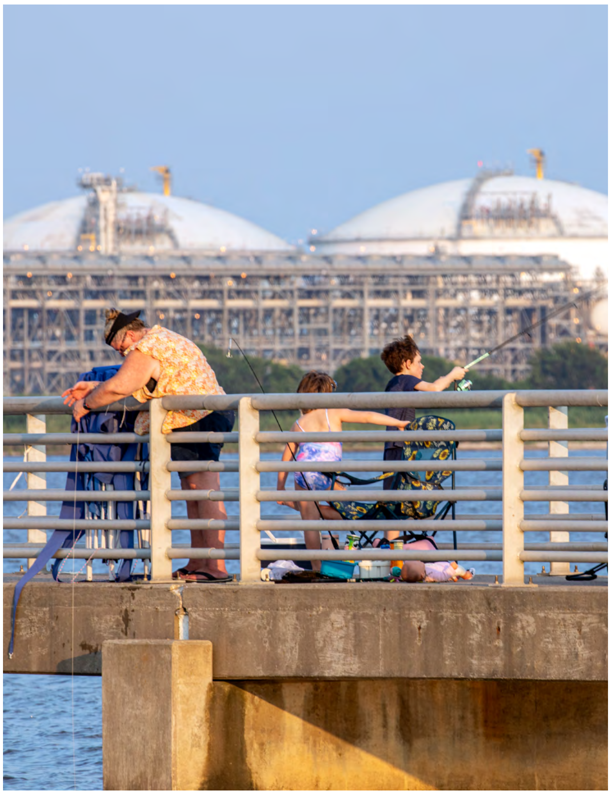
**3. Reform of standards**
Even with industry and government claims of continual improvement, it's plain to see how deaths keep occuring and accidents and near misses persist. Continued reform and updating of international shipping safety and operational standards such at the IMO's IGF and IGC codes and the IACS guidance, along with country specific safety standards, is needed to avoid future incidents and disasters. These measures must be framed as temporary risk mitigation steps while transitioning away from LNG entirely and rapidly.

**4. Stringent Siting Requirements**
The world needs no more LNG infrastructure, but in cases of expansion in defiance of climate science and several safety issues, minimum standards for locating, siting, and bunkering LNG facilities and activities need to be drastically improved and updated. Community impacts and even deaths from accidents, not to mention air and environmental pollution, could be substantially reduced by putting in place regulations to move these risks away from people and nature. However, the reduction is a necessary but insufficient step toward the ultimate goal: eliminating LNG infrastructure altogether.

**5. Comprehensive Risk Assessments**
There is a need to close the gaps and harmonize LNG safety standards across maritime and land-based port operations. In the short term, current safety frameworks would benefit from improved quantitative risk assessments, which could better define safety and hazard zones around LNG storage and bunkering activities. Prioritizing these assessments should not distract from the urgent need to phase out LNG and invest in renewable energy solutions.

**6. Halting Methane Slip**
Leakage of methane throughout the LNG supply chain can contribute to an increase in accidents (vaporizing gas and flammable gas clouds) and significant release of GHG emissions and air pollution into the atmosphere and local airsheds. Mandating reporting, increasing detection and inspection, and calling for strident methane reduction targets can mitigate some immediate harms. These measures must align with a broader strategy to end LNG production and consumption altogether.

**7. Focus on Prevention for Emergency Response**
Prevention is the most effective emergency response, and by eliminating methane slip, increasing operational transparency, and moving bunkering and operations away from communities and biodiversity hotspots are essential components of reformed and improved emergency response planning and communications. However, no new LNG operations or shipping should be approved under any circumstances, regardless of mitigation efforts.



**Above & below: People fish in Walter Umphrey Park on the Texas side of Sabine Lake, across from the Cheniere LNG plant in Cameron, Louisiana.**

**8. Creating a Safety Culture**

People are at the heart of any LNG operation and adequately supporting their needs is a major component of improving safety standards and reducing risks and accidents. Cost-cutting strategies at LNG facilities can result in understaffing, procedural errors, and employee fatigue all of which increase the risk of accidents. Meaningfully ramping up the engagement of workers to develop human centered procedures, and having adequate training coupled with programs that are explicitly designed to avoid fatigue and burnout are needed to create a safety culture in many LNG related activities. However, the focus must remain on transitioning away from LNG to eliminate these risks at their source.

**9. Climate Proof**

Climate risk assessments and resilience measures need to be added and incorporated to protocols, codes, standards and regulations, requiring facilities and operations both on land and at sea to implement both physical and operational modifications that account for potential impacts of climate change on port infrastructure and LNG transfer operations. Additionally, fully accounting for methane leaks and GHG emissions from the full cycle or all LNG operations is essential in transitioning to zero emission and zero methane economies.
LNG and other fossil fuels are fundamentally incompatible with the urgent need to transition to a fully renewable energy system. There is no room for new fossil fuel projects in a world that must rapidly decarbonize to meet climate targets and prevent catastrophic global warming.

The risks posed by LNG—ranging from methane emissions and safety hazards to ecological destruction—demand not only stricter interim measures but a decisive and immediate commitment to phase out LNG infrastructure altogether. Governments must prioritize renewable energy investments and policies that ban new fossil fuel projects, halt the expansion of existing operations, and accelerate the shift toward a just and equitable zero-emissions future.

Addressing the LNG industry's immediate risks is a critical but temporary step. The ultimate goal must remain clear: ending reliance on fossil fuels, including LNG, and achieving a sustainable, just and equitable energy system that protects both people and the planet.

# 9. References


American Petroleum Institute (API). 2021. “API Standards: International Usage and Deployment”. Available at: https://www.api.org/-/media/APIWebsite/products-and-services/API-International-Usage-and-Deployment-Report-2022.pdf

Aneziris, O. 2019. “SUPER-LNG overview and guidelines for LNG port Safety”. SUPER-LNG -SUstainability PERformance of LNG-based maritime mobility, Available at: https://superlng.adrioninterreg.eu/wp-content/uploads/2019/10/02_SUPER_LNG_CONFERENCE_Aneziris_15_10_2019.pdf

Aneziris O. Koromila, I., and Nivolianitou, Z. 2020. “A systematic literature review on LNG safety at ports. Safety Science”, 124, 104595. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0925753519322064

Animah, I. and Shafiee, M. 2020. “Application of Risk Analysis in the Liquefied fossil gas (LNG) Sector: An Overview”. Journal of Loss Prevention in the Process Industries. 63:103980. DOI: https://doi.org/10.1016/j.jlp.2019.103980.

BBC. 2020. China explosion – Tanker truck blows up, killing 19 people. Available at: https://www.bbc.com/news/world-asia-china-53039831

Blanchat, T. Hightower, M., Luketa, A. 2014. “LNG Use and Safety Concerns”. Sandia National Laboratories, NARUC Commissioner Joint Meeting with LNG Working Group, Available at: https://www.osti.gov/servlets/purl/1367739

Bohacikova, V. 2024. “Key lessons from LNG incidents for safer operations”. Available at: https://www.gexcon.com/blog/key-lessons-from-lng-incidents-for-safer-operations/

Carr, E. W., McCabe, S. J., Elling, M., and Winebrake, J. J. 2023. “Options for Reducing Methane Emissions from New and Existing LNG-Fueled Ships”. Available at: https://theicct.org/wp-content/uploads/2023/10/Options-for-Reducing-Methane-Emissions-from-New-and-Existing-LNG-Fueled-Ships-FINAL-926.pdf

Carr, E. W., Winebrake, J. J., McCabe, S. J., and Elling, M. 2024. “Analysis of Liquefied fossil gas as a Marine Fuel in the United States”. EERA & Ocean Conservancy. Available at: https://oceanconservancy.org/wp-content/uploads/2024/04/Final-LNG-as-a-Marine-Fuel-in-the-United-States.pdf

Cedre 2024. Flinterstar/Al Oraiq. Available at: https://wwz.cedre.fr/en/Resources/Spills/Spills/Flinterstar-Al-Oraiq

City of Hyattsville. 2005. Statement of Qualifications – CH IV International. Available at: https://www.hyattsville.org/Archive/ViewFile/Item/425

Cherigui, B. 2022. “The ship-port interface safety management: case study of LNG ports and marine terminals in Algeria ports and marine terminals in Algeria”. Available at: https://commons.wmu.se/cgi/viewcontent.cgi?article=3123&context=all_dissertations

CHPNY and PSR. 2023. “Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking and Associated Gas and Oil Infrastructure”. Available at: https://concernedhealthny.org/wp-content/uploads/2023/10/CHPNY-Fracking-Science-Compendium-9.pdf

Coote, B. 2016. “Surging Liquefied fossil gas Trade – How US Exports Will Benefit European and Global Gas Supply Diversity, Competition, and Security”. Atlantic Council. ISBN: 978-1-61977-962-4. DOI: http://www.jstor.com/stable/resrep03638.1

Court of Common Pleas of Philadelphia County. 2021. BRIAN DIU v. PHILADELPHIA GAS WORKS. Available at: https://www.smbb.com/wp-content/uploads/2021/11/Complaint-TS-11-17-21.pdf

Earth Insight, SkyTruth. 2024. “Coral Triangle at Risk: Fossil Fuel Threats and Impacts”. Available at: https://assets.takeshape.io/17e2848c-4275-4761-9bf5-62611d9650ae/dev/fbd728bf-566c-409b-914d-a0d982c5dc01/Coral%20Triangle%20Risk%20Assessment.pdf

Englund, W. 2021. “Engineers Raise Alarms Over the Risk of Major Explosions at LNG Plants”. The Washington Post. Available at: https://www.washingtonpost.com/business/2021/06/03/lng-export-explosion-vce/

ERM. 2018. Annex 5C – Summary of Industry Incidents Review. Environmental Resources Management, Hong Kong. Available at: https://www.epd.gov.hk/eia/register/report/eiareport/eia_2562018/HTML/Section%205/0359722_Annex5C.pdf

EU Document 52021DC0599. 2018. “Efficient Functioning of Directive 2012/18/EU”. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0599

European Committee for Standardization (CEN). 2021. “Installation and equipment for liquefied fossil gas – Design of onshore”. Available at: installations. https://standards.cencenelec.eu/dyn/www/f?p=CEN:110:0::::FSP_PROJECT,FSP_ORG_ID:63493,6263&cs=1D603C11CF9E37BC2595E1AFA7D18B508

European Maritime Safety Agency (EMSA). 2018. “Guidance on LNG Bunkering to Port Authorities and Administrations”. Available at: https://www.emsa.europa.eu/publications/inventories/item/3207-guidance-on-lng-bunkering-to-port-authorities-and-administrations.html

Gerbec M., and Aneziri O. 2020. “Guidelines for Safety Reporting of LNG Infrastructure in Port Areas”. Available at: https://superlng.adrioninterreg.eu/wp-content/uploads/2020/12/SUPERLNG_WPT2_HBP_DT231_0806020_3_3_final.pdf

GIIGNL. 2019. “Managing LNG Risks – Information Paper #4”. Available at: https://giignl.org/wp-content/uploads/2021/10/giignl2019_infopapers4.pdf

Government of Canada. 2024. “Validation of recommended emergency actions for liquefied fossil gas (LNG) in the Emergency Response Guidebook (ERG)”. Available at: https://tc.canada.ca/en/dangerous-goods/publications/research-summary-validation-recommended-emergency-actions-liquefied-natural-gas-lng-emergency-response-guidebook-erg

Ha, S-m. Lee, W-J., Jeong, B., Choi, J-H., Kang, J.. 2019. “Regulatory Gaps between LNG Carriers and LNG Fuelled Ships”. Available at: https://strathprints.strath.ac.uk/66813/1/Ha_etal_JMET_2019_Regulatory_gaps_between_LNG_carriers_and_LNG_fuelled_ships.pdf

Heureaux-Torres,J., Chang, A., Donaghy, T. Sierra Club and Greenpeace USA. 2024. “Permit to Kill: Potential Health and Economic Impacts from U.S. LNG Export Terminal Permitted Emissions. Sierra Club and Greenpeace USA. Available at: https://www.greenpeace.org/static/planet4-usa-stateless/2024/11/47b90812-permit-to-kill.pdf

Howarth, R.W. 2024. “The greenhouse gas footprint of liquefied fossil gas (LNG) exported from the United States”. Energy Sci Eng. 1-17. doi:10.1002/ese3.1934

IACS 2016. “LNG Bunkering Guidelines”. Available at: http://gasnam.es/wp-content/uploads/2018/10/rec_no_142_pdf2936-2.pdf

IFO Group. 2022. “Loss of Primary Containment Incident Investigation Report”. IFO Group – Safety, Risk & Fire Consultants. Available at: https://subscriber.politicopro.com/eenews/f/eenews/?id=00000184-7d8d-d7f7-a79c-ff8f6e230001

IGC Code. 2016. “The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk”. International Maritime Organisation, Available at: https://www.imo.org/en/ourwork/safety/pages/igc-code.aspx

IGF Code. 2024. “International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels”. International Maritime Organisation, Available at: https://wwwcdn.imo.org/localresources/en/publications/Documents/Supplements/English/QQ109E_supplement_January2024_PQ.pdf

India Oil Industry Safety Directorate. n.d. Available at: https://www.oisd.gov.in/oisd-standards-list

Koo J., Kim, H.S., So, W., Kim, K.H., Yoon, E.S. 2009. “Safety Assessment of LNG Terminal Focused on the Consequence Analysis of LNG Spills”. Proceedings of the 1st Annual Gas Processing Symposium 10–12 January 2009, Doha, Qatar, Available at: https://www.sciencedirect.com/science/article/abs/pii/B9780444532923500407

Li, L., Luo,J., Wu, G., Li, X., Ji, N., Zhu, L. 2021. “Impact Assessment of Flammable Gas Dispersion and Fire Hazards from LNG Tank Leak”. Available at: https://doi.org/10.1155/2021/4769552

Lieb, J.M. 2001. “Recent Developments in API Storage Tank Standards to Improve Spill Prevention and Leak Detection/Prevention”. Available at: https://archive.epa.gov/emergencies/content/fss/web/pdf/liebpaper.pdf

Liquefied Gas Carrier National Center of Expertise (LGCNCOE). 2009. Available at: https://www.dco.uscg.mil/lgcncoe/

Liu H., Zhu, G., Zhang, M., Shen, J. and Zhang, X. 2019. “Research on Optimization of LNG pressure control safety accessories based on fault tree analysis”. IOP Conf. Series: Earth and Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028

Mandel, J. 2019. “Trump LNG Rule: Will It Address ‘Catastrophic’ Risks?”. E&E News. Available at: https://web.archive.org/web/20190722172209/https://www.eenews.net/stories/1060771257

Ministry of Energy and Energy Affairs. 2015. “Trinidad and Tobago Gas Master Plan”. Available at: https://www.energy.gov.tt/wp-content/uploads/2020/01/Trinidad-and-Tobago-gas-master-plan-2015.pdf

Murphy M.J., Ketola, H.N., Raj, P.K. 1995. “Clean Air Program: Summary Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel”. U.S. Department of Transportation, Federal Transit Administration. DOI: https://doi.org/10.21949/1403909

NRT-RRT. 2016. “Emerging Risks Response Awareness Training Liquefied fossil gas”. U.S. National Response Team. Available at: https://www.nrt.org/sites/2/files/NRT%20Training%20Subcommittee%20LNG%20presentation%20FINAL%202.pdf

Occupational Safety and Health Standards (OSHS). 2007. “Storage and handling of liquefied petroleum gases”. Available at: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.110

Parfomak, P.W. 2003. “Liquefied fossil gas (LNG) Infrastructure Security: Background and Issues for Congress”. Library of Congress – Congressional Research Service. Available at: https://apps.dtic.mil/sti/pdfs/ADA426272.pdf

Raj P.K. and Lemoff, T. 2009. “Risk analysis based LNG facility siting standard in NFPA 59A”. Journal of Loss Prevention in the Process Industries, Volume 22, Issue 6, pg. 820-829. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0950423009001363

Rao, S. 2023. U.S. DOT Finally Suspends LNG-by-Rail Rule! NRDC. Available at: https://www.nrdc.org/bio/sahana-rao/us-dot-finally-suspends-lng-rail-rule

Saha, R., Bullard, R.D., and Powers, L.T. 2024. “Liquefying the Gulf Coast – A Cumulative Impact Assessment of LNG Buildout in Louisiana and Texas”. Texas Southern University. Available at: https://assets.website-files.com/614d88a190900e498857f581/6639c31c3d85f1337ca718c1_Bullard%20Center%20Liquefying%20the%20Gulf%20Coast%20Report%20may%202.pdf

Schneider, S. 1977. “Hazards of LNG Operations Include Collision, Component Failure, Earthquakes and Sabotage”. Daily Nexus. University of California Santa Barbara. URL: https://www.jstor.org/stable/community.33109987

SGMF. 2024. “LNG as a marine fuel – Safety and Operational Guidelines – Bunkering”. Available at: https://sgmf.info/new-sgmf-publication-provides-expansive-and-highly-relevant-guidelines-on-safe-bunkering-of-lng/

SIGTTO. 2024. “Gas as Fuel on Gas Carriers – Review of Practice”. Available at: https://www.sigtto.org/publications/gas-as-fuel-on-gas-carriers-review-of-practice/

Siu N., Herring, S., Cadwallader, L., Reece, W., and Byers, J. 1999. “Qualitative Risk Assessment For An LNG Refueling Station And Review Of Relevant Safety Issues”. Available at: https://www.osti.gov/servlets/purl/1186866

The Danish Maritime Authority. 2012. “North European LNG Infrastructure Project”. Available at: http://www.anave.es/images/seguridad/danish_maritime_authority-north_european_lng_infrastructure_project-mar_12.pdf

The Japan Gas Association. n. d. Available at: https://www.gas.or.jp/en/

Tobar, M. 2024. “The Gulf Coast’s Battles Against Climate Change and LNG”. Available at: https://www.greenpeace.org/usa/the-gulf-coasts-battles-against-climate-change-and-lng/

U. S. Government Accountability Office. 2007. “Public Safety Consequences of a Terrorist Attack on a Tanker Carrying Liquefied fossil gas Need Clarification”. Available at: https://www.gao.gov/new.items/d07316.pdf

van der Vegt, R. G. 2018. “Risk Assessment and Risk Governance of Liquefied fossil gas Development in Gladstone, Australia: Risk Assessment and Risk Governance of LNG Development”. Risk Analysis 38, no. 9: 1830–46. DOI: https://doi.org/10.1111/risa.12977

Wingrove, M. 2024. “LNG-capable bulker collision raises questions on LNG tank location”. Available at: https://www.rivieramm.com/news-content-hub/news-content-hub/bulker-collision-raises-questions-on-lng-tank-location-81752

Wood, M., Guagnini, E., and Major Accidents Hazards Bureau. 2019. “Setting the scene: Major accidents and establishments associated with biogas and LNG May 2019”. Available at: https://unece.org/sites/default/files/datastore/fileadmin/DAM/env/documents/2019/TEIA/Seveso-Seminar-Presentation-01-LNG-Biogas_Set-Scene-MAHB__1_.pdf

World Bank Group. 2009. “Environmental, Health, and Safety Guidelines for Liquefied fossil gas (LNG) Facilities”. Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/606041484215593420/environmental-health-and-safety-guidelines-for-liquefied-natural-gas-lng-facilities

---

Figure 1: NRT-RRT (2016) . Emerging Risks Response Awareness Training Liquefied fossil gas. U. S. National Response Team (page 12). Available at: https://www.nrt.org/sites/2/files/NRT%20Training%20Subcommittee%20LNG%20presentation%20FINAL%202.pdf

Figure 2: Based on: NRT-RRT (2016) . Emerging Risks Response Awareness Training Liquefied fossil gas. U. S. National Response Team (pp. 16ff). Available at: https://www.nrt.org/sites/2/files/NRT%20Training%20Subcommittee%20LNG%20presentation%20FINAL%202.pdf

Figure 3: Howarth RW. The greenhouse gas footprint of liquefied natural gas (LNG) exported from the United States. Energy Sci Eng. 2024; 12: 4843-4859. doi:10.1002/ese3.1934

Figure 4: Visualization of the reports' own results.

# Appendix

**Table A1: Summary of LNG Industry Accidents listed in chronological order.**

| | | | | |
|---|---|---|---|---|
| **Date** | 1944 | 1964 / 1965 | 1964 / 1965 | 1965 |
| **Location** | United States | Algeria | Algeria | United Kingdom |
| **Facility Name** | East Ohio Gas LNG Tank | Methane Progress LNG Carrier Vessel | Jules Verne LNG Carrier | LNG carrier (no name) Marine Transportation / Facility |
| **Facility Type** | Storage / Liquefaction Regasification / Import | Marine Transportation / Facility | Marine Transportation / Facility | Regasification / Import |
| **Accident** | Explosion / Fire | Fire | Methane Leak Explosion | Fire |
| **Description** | Gas leak from LNG storage tank combusted when mixed with air, leading to an explosion of the tank, with a second tank exploding shortly after. The fire spread 20 blocks and burned for two days. The vapourized gas flowed into sewers, leading to secondary explosions. | Lightning struck while the LNG carrier was being loaded and ignited routine vapour venting – occurred in 1964 and 1965. | LNG spill occurred resulting from overflowing cargo tank, resulting in fracture of cover plating of tank and adjacent deck plating. | LNG released and ignited during LNG transfer operation. |
| **Cause** | Mechanical / Material failure | Weather and natural conditions | Human / Operator error | Human / Operator error |
| **Impact** | • Fatalities: 130 (98 employees)<br>• Missing: 32<br>• Injuries: 251 hospitalised and 150 field treated<br>• Environmental impact: 1.1 million gallons of LNG released<br>• Material damage: 81 homes destroyed, 32 homes partially destroyed; 2 factories destroyed, 13 factories partially destroyed; 217 cars; 7 large trailers; 1 large tractor | Not reported | • Environmental Impact: gas / methane leak<br>• Material damages: ship damages (tank and deck) | • Injuries: 1<br>• Environmental impact: gas / methane leak<br>• Material damages: Not disclosed |
| **Estimated Financial Loss** | $6,800,000.00 | Not reported | Not reported | Not reported |
| **References** | • 1944 Cleveland LNG Incident_Lessons Learnt_ Risk and Safety Blog.pdf [A04] EAST OHIO GAS CO. EXPLOSION AND FIRE_ Encyclopedia of Cleveland History_Case Western Reserve University.pdf<br>• East Ohio Gas Explosion, October 20, 19...e and Report – Cleveland Police Museum. pdf [A04] The East Ohio Gas Company Explosion _ Cleveland Historical.pdf<br>• Qualitative Risk Assessment for an LNG Refueling Station And Review of Relevant Safety Issues_Idaho National Engineering and Environmental Laboratory. pdf<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications.pdf | • Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• Shuttleworth, H. (2017). Heat from Cold. Shipping Today and Yesterday. | • Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy |

| Date | 1965 / 1974 / 2003 | 1966 | 1968 | 1968 |
|---|---|---|---|---|
| Location | Not reported | Not reported | United States | Italy |
| Facility Name | Methane Princess LNG Carrier Vessel | Methane Progress LNG Carrier Vessel | LNG Storage tank | Panigaglia Regasification Plant |
| Facility Type | Marine Transportation / Facility | Marine Transportation / Facility | Storage / Liquefaction | Regasification / Import |
| Accident | Methane Leak<br>Fire / Explosion<br>Marine Incident | Marine Incident | Explosion | Methane Leak |
| Description | • 1965: LNG loading arms disconnected before liquid lines had been drained, causing LNG to pass into a stainless steel drip pan beneath loading arms, eventually causing a fracture in the deck plating.<br>• 1974: Methane Priness rammed by freighter (Tower Princess) while moored at Canvey Island LNG Terminal, creating 3 foot gash in hull (no LNG released)<br>• 2003: Fire on board while under construction burnt part of cargo tanks (minor damage). Mechanical / Material failure | Cargo leakage reported. No details. | Fossil gas backed through no-longer isolated line and partially open valve, accumulating in an aluminum tank and was ignited from an unspecified source causing an explosion. | Limited information: Misfiling operation, 2000 t of LNG leak in tank roll |
| Cause | Human / Operator error<br>Marine Incident | Not reported | Human / operator error | Human / Operator error |
| Impact | • Environmental impact: gas / methane leak<br>• Material damages: ship damage | | • Fatalities: 4<br>• Environmental impact: methane release | Environmental impact: gas released |
| Estimated Financial Loss | Not reported | Not reported | Not reported | Not reported |
| References | • Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• Ship Technology (2014). Methane Princess LNG Carrier.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Siu et al. (1999) Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues. Idaho National Engineering and Environmental Laboratory. Prepared for the US Department of Energy. | Hongkai Liu et al. (2019). Research on Optimization of LNG pressure control safety accessories based on fault tree analysis. IOP Conf. Series: Earth and Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028 |

| **Date** | 1968 | 1969 | 1969 / 1999 / 2001 | 1970 |
|---|---|---|---|---|
| **Location** | Mexico | United States | Not reported | Japan |
| **Facility Name** | Aristotle LNG Tank | LNG Tank under construction | Polar Alaska LNG Tank | Not reported |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Marine Incident | Explosion<br>Methane Leak | Methane Leak | Marine Incident |
| **Description** | Vessel ran aground off the coast of Mexico, and the bottom was damaged. No LNG released. | fossil gas flowed into a tank while it was under construction, causing an explosion to occur. | • 1969: Sloshing of LNG heel in tank caused part of the supports for the cargo pump electric cable tray to break loose, resulting in perforations of the primary barrier. LNG leaked into the interbrier space. No LNG released.<br>• 1999: Engine failed during approach to the Atlantic LNG Jetty (Trinidad and Tobago). It struck and damaged the Petrotrin pier, but no LNG was released.<br>• 2001: Vessel collided with a bulk carrier at sea (in ballast), which caused minor hull damage and sustained holing to the bow. There were 3 injuries and 1 fatality of the bulk carrier crew, though no spillage was recorded. | A few hours out of Japan heavy seas caused sloshing of cargo tanks in LNG ship steaming from Japan to Alaska. A thin membrane wall bent in four places and a half inch crack formed in a weld seam. |
| **Cause** | Not reported | Human / Operator error | Not reported | Weather and natural conditions |
| **Impact** | Material damages: Vessel bottom damage | • Environmental impact: gas / methane leak<br>• Material damages: Vessel damage | • Fatalities: 1<br>• Injuries: 3<br>• Material damages: Vessel damage; port damage | Material damages: membrane wall bent in four places and a crack formed in a well seam |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy | • City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. |

| | | | | |
|---|---|---|---|---|
| **Date** | 1970 / 2004 | 1971 | 1971 | 1971 |
| **Location** | Not reported | Italy | United States | Not reported |
| **Facility Name** | Arctic Tokyo | LNG Ship Esso Brega, La Spezia LNG Import Terminal | Capitol / Capital LNG Tanker Truck | Descartes LNG Tank |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Land Transportation | Marine Transportation / Facility |
| **Accident** | Methane Leak / Fire | Methane Leak | Collision / Rollover | Methane Leak |
| **Description** | • 1970: Sloshing of LNG heel in tank during bad weather caused local deformation of primary barrier and supporting insulation boxes. LNG leaked into the interbarrier space at one location. No LNG released.<br>• 2004: Vessel had minor fire break out after being struck by lighting during discharge. Slight damage to the vessel, but no casualties or spillage. | Heavy LNG unloaded into a storage tank. After 18 hours, the tank developed a sudden increase in pressure causing LNG vapour to discharge from tank safety valves and vents over several hours.. | Blowout, hit rocks by road, tore a hole in the tank, 20 % spilled, no fire, remainder dumped. Single wall tanker. | A fault in the connection between the primary barrier and the tank dome allowed gas into the interbarrier space. Crew reportedly tried to conceal the leak from authorities. |
| **Cause** | Weather and natural conditions | Mechanical / Material failure | Mechanical / Material failure | Mechanical / Material failure |
| **Impact** | Material damages: vessel damage | • Environmental impact: Large volume gas / methane leak (2000 tons of LNG leaked)<br>• Material damages: Tank roof slightly damaged | • Environmental impact: LNG spilled (20 % of cargo spilled, remainder dumped)<br>• Material damages: hole in tank | Not available |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | • City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• Riviera Newsletter. (2012) An LNGC quartet like no other.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Hongkai Liu et al. (2019). Research on Optimization of LNG pressure control safety accessories based on fault tree analysis. IOP Conf. Series: Earth and<br>• Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028 | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. |

| Date | 1971 | 1971 / 1974 (2) | 1972 | 1973 |
|---|---|---|---|---|
| **Location** | United States | United States | Canada | United States |
| **Facility Name** | Indianhead LNG Tanker Truck | Gas Inc. LNG Tanker Truck | LNG Plant in Montreal by Gaz Metropolitain | LNG Storage tank on Staten Island by Texas Eastern Transmission Company and satellite company Texas Eastern Cryogenics Company |
| **Facility Type** | Land Transportation | Land Transportation | Storage / Liquefaction | Storage / Liquefaction |
| **Accident** | Collision / Rollover / Fire | Methane Leak | Explosion / Fire | Explosion / Fire |
| **Description** | Head-on collision with truck. Gasoline and tire fire, no cargo lost. | • 1971: Driver fatigue, drove off road, rollover cracked fittings, small gas leak, no fire.<br>• 1974: faulty brakes caused wheel fire. Check valve cracked 5 % leaked out. No fire. In the same year and month but different city, the truck loose valve leaked LNG during transfer operations. | Unodorized gas vented into the control room where employees were smoking, causing an explosion. | LNG storage tank was leaking LNG through the liner. A 10 ft long rip was found in the liner bottom, and repair and augmentation work commenced. About 11 months after the repair work, a fire swept through the tank. The overpressure caused by hot combustion products in the tank caused the tank roof to raise. The roof fractured and fell in pieces back into the tank. The fire is believed to have been an insulation fire, accelerated by trapped pockets of methane gas that lingered from when LNG had leaked into the insulation while the liner had been breached. |
| **Cause** | Human / Operator error | Human / Operator error<br>Mechanical / Material failure | Human / Operator error | Human / Operator error |
| **Impact** | • Environmental impact: smoke<br>• Material damages: truck damage | • Environmental impact: gas leak<br>• Material damages: crack in fittings; check valve cracked | • Fatalities: 1<br>• Injuries: 5<br>• Environmental impact: release of fossil gas<br>• Material damage: control room panels and plastic instrument faces | • Fatalities: 40<br>• Injuries: 3<br>• Environmental impact: smoke<br>• Material damage: tank, pipeline; wreckage away from the site |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • Siu et al. (1999) Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues. Idaho National Engineering and Environmental Laboratory. Prepared for the US Department of Energy.<br>• Hongkai Liu et al. (2019). Research on Optimization of LNG pressure control safety accessories based on fault tree analysis. IOP Conf. Series: Earth and Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028 | • Siu et al. (1999) Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues. Idaho National Engineering and Environmental Laboratory. Prepared for the US Department of Energy.<br>• Perlmutter, E. (1973). S. I. Blast is Laid to Trapped Gas. The New York Times.<br>• Zaffarano, S. (2021). 48 years ago: Staten Island Liquefied Natural Gas Explosion in Kills 40 Workers. Silive. |

| Date | 1973 | 1973 / 1977 | 1973 / 1976 / 1981 | 1974 |
|---|---|---|---|---|
| **Location** | United Kingdom | Land Transportation | United States | Algeria |
| **Facility Name** | Not reported | Chemical Leaman LNG Tank Truck | Andrews & Pierce LNG Tank Truck | Methane Progress LNG Carrier Vessel |
| **Facility Type** | Not reported | United States | Land Transportation | Marine Transportation / Facility |
| **Accident** | Explosion | Collision / Rollover | Collision / Rollover | Other |
| **Description** | Small amount of LNG spilled upon a rainwater puddle, resulting in flameless vapour explosion (rapid phase transition). | • 1973: driver couldn't negotiate turn off. Rollover demolished tractor and severe damage to trailer. No fire. $40,000 damage to trailer.<br>• 1977: truck parked (with blowout) hit by a tow truck in rear. No leak or fire. | • 1973: truck side swiped parked car; brakes locked and trailer overturned. No cargo onboard, no fire.<br>• 1976: car hit trailer at landing wheels, rollover, no LNG loss or fire.<br>• 1981: rain and poor road conditions. Led to rollover. No fire, no product loss (empty), driver not seriously hurt. Extensive damage to transport. | LNG carrier vessel touched bottom at port. |
| **Cause** | Not reported | Human / Operator error | • Human / Operator error<br>• Weather / natural conditions<br>• Other | Marine incident |
| **Impact** | • Environmental impact: gas / methane leak<br>• Material damages: Glass breakage | Material damages: tractor demolished and severe damage to trailer | Not reported | Material damages:<br>Ship damage (damaged rudder) |
| **Estimated Financial Loss** | Not reported | $40,000+ | Not reported | Not reported |
| **References** | Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy |

| Date | 1974 | 1974 (2) | 1975 / 1976 / 1977 / 1981 | 1977 |
|---|---|---|---|---|
| **Location** | United States | Not reported | United States | Algeria |
| **Facility Name** | Massachusetts Barge | Euclides LNG Tanker | LP Transport LNG Tank Truck | Arzew Gas Terminal |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Land Transportation | Liquefaction / Export |
| **Accident** | Methane Leak | Marine Incident<br>Collision / Rollover | Collision / Rollover | Methane Leak / Explosion |
| **Description** | LNG was being loaded onto the barge. A power failure led to the automatic closure of the main liquid line values, resulting in a pressure surge which caused LNG to leak through the valve. Several fractures occurred in the deck plates. | In August 1974, damage caused by contact with another vessel, causing damage to bulwark plating and roller fairlead. No LNG released.<br>In September of the same year, ran aground at Le Havre, France. Damaged bottom and propeller. No LNG released. | • 1975: rollover, no fire. Driver swerved to avoid the pedestrian, hit the guardrail and rolled over and down an 80 foot bank. $18,000 damage to trailer.<br>• 1976: rollover, no fire, caused by oil spill on exit ramp. Truck righted and continued delivery of cargo.<br>• 1977: “Single Wall” Lubbock hit in rear by tractor-trailer, axle knocked off. Rollover. No loss of cargo.<br>• 1981: driver failed to negotiate turn due to excessive speed on country road. Driver not seriously injured. Loss of some product through the relief valve resulted in serious damage to transport. | Aluminum valve ruptured, leading to several thousand cubic metres of LNG being released over 10 hours. The leak occurred on the ground, near a frozen soil tank, and the LNG pool spread onto the sea, with several rapid phase transitions observed. |
| **Cause** | Mechanical / Material failure | Not reported | Other<br>Human / Operator error | Mechanical / Material failure |
| **Impact** | • Environmental impact: gas / methane leak<br>• Material damages: fractures to deck plates | Material damages: Damage to bulwark planing and roller fairleads; damage to bottom and propeller | • Injuries: 1<br>• Environmental impact: LNG leak<br>• Material damages: trailer damage; serious damage to transport | • Fatalities: 1 (frozen to death)<br>• Environmental impact: 2x103 cubic metres of LNG leaked<br>• Material damages: Glass breakage |
| **Estimated Financial Loss** | Not reported | Not reported | $18,000 + | Not reported |
| **References** | • Appendix R: Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • Nédelka, D.; Sauter, V.; Goanvic, J.; Ohba, R. (2003) Last developments in Rapid Phase Transition knowledge and modeling techniques. Offshore<br>• Technology Conference Offshore Technology Conference – Houston, Texas. Offshore Technology Conference. doi:10.4043/15228-ms Appendix R:<br>• Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy |

| Date | 1977 | 1977 / 2021 | 1978 | 1978 / 2001 |
|---|---|---|---|---|
| Location | United States | Indonesia | United Arab Emirates | Singapore |
| Facility Name | Western Gillet / SDG LNG Tank Truck | LNG Aquarius Tankship | Das Island | Khannur LNG Tanker |
| Facility Type | Land Transportation | Marine Transportation / Facility | Liquefaction / Export | Marine Transportation / Facility |
| Accident | Collision / Rollover | Methane Leak | Methane Leak | Marine Incident<br>Methane Leak |
| Description | Rollover with little product loss, no vacuum loss, no fire. Driver had 3 broken ribs. | 1977: LNG Aquarius tankship overfilled a tank while loading. The high level alarms failed, allowing LNG to spill on the tank cover plating.<br>2021: LNG tanker experienced a steam pipe leak incident. | A bottom pipe connection of an LNG tank failed, resulting in an LNG spill inside the tank containment. A large vapour cloud resulted and dissipated without ignition. | • 1978: The vessel collided with cargo ship Hong Hwa in the Strait of Singapore. Minor damage. No LNG released.<br>• 2001: An LNG leak through a vent during unloading. There were cracks in the tank dome and over-pressurization of cargo in the No.4 tank. A LNG spill was experienced. |
| Cause | Not reported | Mechanical / Material failure | Mechanical / Material failure | Not reported |
| Impact | • Injuries: 1<br>• Environmental impact: LNG leak | Environmental impact: LNG spill | Environmental impact: gas released | • Environmental impact: LNG / methane leak<br>• Material damages: vessel damage, cracks in the tank dome, and over-pressurization of cargo |
| Estimated Financial Loss | Not reported | Not reported | Not reported | Not reported |
| References | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• Editorial Team (2021). Aquarius LNG Tanker Leaks During Operation, PGN Ensures Safe Gas Supply. VOI. | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| | | | | |
|---|---|---|---|---|
| **Date** | 1979 | 1979 | 1979 | 1979 / 1996 / 1998 / 2002 |
| **Location** | United States | United States | Strait of Gibraltar | United States |
| **Facility Name** | LNG Peakshaving Facility in Maryland | Columbia LNG Corporation Terminal | El Paso Paul Kayser Ship | Mostafa Ben-Boulaid Ship |
| **Facility Type** | Regasification / Import Storage / Liquefaction | Storage / Liquefaction | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Explosion | Methane Leak / Explosion Fire | Other | Methane Leak Fire |
| **Description** | Booster pump seal leak at electrical cable penetration point had LNG leak into the junction box, and subsequently the station pump house. An operator depressed the circuit breaker interlock release, and an explosion followed. Transformer oil spread over the area and ignited. | An explosion caused by LNG vapours destroyed a transformer building. Odourless LNG leaked through an inadequately tightened LNG pump seal, vapourized, passed through approximately 210 ft of underground electrical conduit, and entered the substation building, where it was ignited. Fire followed the explosion. | The ship was grounded on a rock while proceeding at speed on loaded passage and manoeuvring to avoid another vessel. The incident resulted in extensive damage to the flat bottom and ballast tanks over a length of almost 500 ft and distortion to the inner hull of the cargo tanks. However, there was no release of cargo. | • 1979: The Mostafa Ben-Boulaid ship had an LNG leakage from the spindle of a swing check valve during unloading at Cove Point, Maryland. The spill caused minor cracking on the steel deck plate.<br>• 1996: Electrical fire in the main engine room while at the quay discharging caused power loss, but no spillage.<br>• 1998: Vessel had generator problems at port, but no spillage or casualty.<br>• 2002: LNG spillage resulted in a cracked deck. |
| **Cause** | Human / Operator error | Human / Operator error | Marine Incident | Mechanical / Material failure Human / Operator error |
| **Impact** | • Fatalities: 1<br>• Injuries: 1<br>• Environmental Impact: Gas / methane leak<br>• Material damage: structural (substation building, electrical transformers, adjacent structures) | • Fatalities: 1<br>• Injuries: 1<br>• Environmental impact: Gas released<br>• Material damages: Substation building and adjacent transformers destroyed; severe damage to roof of vaporizer unit; damage to compressor building; roof of second-stage high pressure pump house damated; severe damage to portable compressor and other equipment; section of fence blown down, with debris as far as 100 ft away. | Material damages: Severe damage to bottom, ballast tank, motor was water damages, and bottom of containment system set up | Material damages: cracking on steel deck plating, power lost, cracked deck |
| **Estimated Financial Loss** | Not reported | $3,000,000 | Not reported | Not reported |
| **References** | • Siu et al. (1999) Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues. Idaho National Engineering and Environmental Laboratory. Prepared for the US Department of Energy.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | National Transportation Safety Board. (1980). Columbia LNG Corporation Explosion and Fire of Substation, Cove Point, Maryland, October 6, 1979. NTSB-PAR-80-2. Washington DC. | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2. Available at: Oil and HNS Spill Plan Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| | | | | |
|---|---|---|---|---|
| **Date** | 1979 / 2000 / 2023 | 1980 | 1980 | 1980 |
| **Location** | United States | South East Asia | Japan | Not reported |
| **Facility Name** | Pollenger Ship | LNG Libra Ship | LNG ship Taurus | El Paso Consolidated LNG Tanker |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Methane Leak | Other | Other | Marine Incident |
| **Description** | • 1979 :LNG spilled from leaking valve gland while the ship was discharging LNG at the terminal, fracturing the tank cover plating.<br>• 2000: An outbreak of fire in the yard caused damage to part of the tank insulation, causing the death of 1 shipbuilder.<br>• 2003: Developed gearbox problems at sea; no spillage or casualty. | The ship experienced a fracture in the propeller shaft, leaving it without propulsion while on a loaded passage from Indonesia to Japan. The complete cargo was transferred to a sister ship. | Heavy weather caused the vessel to become grounded on the rocks at the entrance to Tobata harbour, Japan. The ship suffered extensive damage to the ballast tanks, but the cargo tanks were not damaged and there was no release of LNG. | Minor release of LNG from a flange. Deck plating fractu-red due to low temperature embrittlement. |
| **Cause** | Mechanical / Material failure | Marine Incident | Weather / natural conditions | Mechanical / Material failure |
| **Impact** | • Fatalities: 1<br>• Environmental impact: Gas released<br>• Material damages: fracture of the LNG tank cover plating; damage to tank insulation | Material damages: Propeller shaft fractured | Material damages: Extensive bottom damage; ballast tank all flooding and listing. | Material damages: deck plating fractured |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | • CH IV International – The LNG Specialist. (2014) Safety History of International LNG Operations. Available at: Safety History of International LNG Operations (Mar 2014) - PDFCOFFEE.COM<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2.<br>• Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2.<br>• Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications |

| Date | 1980 | 1983 | 1983 / 2002 | 1984 |
|---|---|---|---|---|
| **Location** | Not reported | Indonesia | Japan (1983)<br>Strait of Gibraltar (2002) | Not reported |
| **Facility Name** | Larbi BEn M'Hidi LNG tanker | LNG Export Facility, Indonesia | LNG Ship Norman Lady | Melrose LNG Tanker |
| **Facility Type** | Marine Transportation / Facility | Liquefaction / Export | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Marine Incident | Explosion / Fire | Marine Incident | Fire / Marine Incident |
| **Description** | Vapour released during transfer arm disconnection. No LNG released. | The main liquefaction column ruptured due to overpressurization of the heat exchanger, caused by a blind left in a flare line during start-up. The incident occurred during dry-out and purging of the exchanger with warm fossil gas prior to introducing LNG into the system, so no LNG was involved or released, but there was an ensuing fire. Debris and coil sections were projected around 50 metres away; shrapnel from the column killed 3 workers. | • 1983: During cooldown of the cargo transfer arms prior to unloading, the ship moved under its own power, sharing all cargo transfer arms and spilling LNG. There was no ignition.<br>• 2002: The ship was struck by the nuclear submarine "USS Oklahoma City". The ship sustained damage but none to the cargo tanks. | There was a fire in the engine room at sea and no structural damage was sustained. No LNG spill or fatality / injury was recorded. |
| **Cause** | Not reported | Mechanical / Material failure | Human / Operator error<br>Mechanical / Material failure | Not reported |
| **Impact** | Not available | • Fatalities: 3<br>• Material damages: Debris and coil sections projected 50 m away. | • Environmental impact: LNG spill<br>• Material damages: all cargo transfer arms sheared; leakage of seawater into double bottom dry tank | Nothing reported |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| | | | | |
|---|---|---|---|---|
| **Date** | 1985 | 1985 | 1985 | 1985 / 2001 |
| **Location** | Not reported | Not reported | United States | Not reported |
| **Facility Name** | Gadinia LNG Tanker | Isabella LNG Tanker | LNG Peakshaving Facility in Pinson, Alabama | Ramdane Abane LNG Tanker |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Storage / Liquefaction | Marine Transportation / Facility |
| **Accident** | Marine Incident | Marine Incident | Fire / Methane Leak / Explosion | Marine Incident |
| **Description** | Steering gear failure. No details of damage reported. | A cargo vale failure lead to an overflow of LNG | The welds on a patch plate on a small aluminum vessel failed as the vessel was receiving LNG being drained from the liquefaction cold box. The plate was propelled into a building that contained the control room, boiler room, and offices. Some of the windows in the control room were blown inward and fossil gas escaping from the failed vessel entered the building and ignited. Six employees were injured. | • 1985: LNG tank collided while loaded, affecting the port bow. No LNG was released.<br>• 2001: An engine breakdown at sea occurred, but no casualties or spillages were reported. |
| **Cause** | Not reported | Not reported | Mechanical / Material failure | Not reported |
| **Impact** | Not reported | • Environmental impact: gas released<br>• Material damages: deck fractures | • Injuries: 6<br>• Environmental impact: gas released<br>• Material damages: windows and other damage in the facility | Material damages: port bow affected |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy | Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy | • City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications<br>• NSTB. Available at: https://www.ntsb.gov/safety/safety-recs/recletters/P86_3_8.pdf | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications |

| **Date** | 1987 | 1987 | 1988 | 1989 |
|---|---|---|---|---|
| **Location** | United States | United States | United States | Algeria |
| **Facility Name** | Liquefied Gaseous Fuels Spill Test Facility Flash Fire in Nevada | Subsea Pipeline in Louisiana | Distrigas of Massachusetts | Tellier LNG Tanker |
| **Facility Type** | Other | Pipelines | Regasification / Import | Marine Transportation / Facility |
| **Accident** | Fire | Explosion | Methane Leak | Explosion / Methane Leak |
| **Description** | LNG intentionally released to conduct vapour barrier tests to mitigate spill dispersion. Accidental ignition occurred after gas flowed over the vapour barrier, igniting methane vapours. | A fishing vessel struck and ruptured a fossil gas liquids pipeline. The resulting explosion killed two crew members. The pipe, installed in 1968, was covered with only 6" of soft mud, having lost its original 3-foot cover of sediments | Approximately 30,000 gallons of LNG were spilled through "blown" flange gaskets during an interruption in LNG transfer. The cause was "condensation induced water hammer". | Moorings failed, and the ship was blown out of the berth during severe winds. Cargo transfer had been stopped before the vessel moved, but the loading arms had not been drained or disconnected. Damage to the loading arms spilled LNG onto the deck, fracturing the steel plate. |
| **Cause** | Human / operator error<br>Mechanical / Material failure | Not reported | Mechanical / Material failure | Weather / natural conditions |
| **Impact** | • Environmental impact: potential gas leak (not disclosed)<br>• Material damage: Not reported | • Fatalities: 2<br>• Environmental impact: gas released<br>• Material damages: pipeline ruptured | Environmental impact: gas released | • Environmental impact: gas released<br>• Material damages: hull and deck fractures; cargo transfer arms sheared; piping on ship heavily damaged |
| **Estimated Financial Loss** | $70,000 - $95,000 | Not reported | Not reported | Not reported |
| **References** | • Siu et al. (1999) Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues. Idaho National Engineering and Environmental Laboratory. Prepared for the US Department of Energy.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications |

| Date | 1989 | 1989 | 1990 | 1992 |
|---|---|---|---|---|
| Location | United Kingdom | United States | Not reported | United States |
| Facility Name | LNG Peakshaving Facility in Thurley, UK | Subsea Pipeline in Sabine Pass, Texas | Bachir Chihani LNG tanker | LNG Facility in Maryland, United States (name not specified) |
| Facility Type | Regasification / Import | Pipelines | Marine Transportation / Facility | Not reported |
| Accident | Methane Leak<br>Fire | Fire | Marine Incident | Methane Leak |
| Description | While cooling down the vaporizers in preparation for sending out fossil gas, low-point drain valves were opened on each vaporizer. One valve had not been closed when the pumps were started and LNG entered the vaporizers and was released into the atmosphere as a high pressure jet. The resulting vapour cloud ignited and flash fire covered an area approximately 40 by 25 m. Two operators received burns. The ignition source was believed to be the pilot light on one of the other submerged combustion vaporizers. | A vessel struck a 16” gas pipeline in shallow water near Sabine Pass, Texas. The vessel was engulfed in flames; 11 of the 14 crew members died. The pipeline, installed in 1974 with 8 to 10 feet of cover, was found to be lying on the bottom, with no cover at all. | A fracture of the inner hull plating led to the ingress of seawater into the space behind the cargo hold insulation while the vessel was in ballast. There was no LNG spillage or fatality / injury reported. | Limited information: The safety valve was not open. After overfilling, the tank wall broke and 95 cubic metres of LNG was leaked. |
| Cause | Human / Operator error | Not reported | Mechanical / Material failure | Human / Operator error |
| Impact | • Injuries: 2<br>• Environmental impact: gas released, smoke<br>• Material damages: 40 x 25 m area burned | • Fatalities: 11<br>• Environmental impact: gas released<br>• Material damages: fire engulfed vessel | Material damages: structural cracks | Environmental impact: gas released |
| Estimated Financial Loss | Not reported | Not reported | Not reported | Not reported |
| References | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Hongkai Liu et al. (2019). Research on Optimization of LNG pressure control safety accessories based on fault tree analysis. IOP Conf. Series: Earth and Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028 |

| Date | 1992 / 2009 | 1993 | 1993 | 1993 / 1994 / 1998 / 2003 |
|---|---|---|---|---|
| **Location** | Not reported | Indonesia | United Kingdom | United States |
| **Facility Name** | Matthew LNG Tanker | Bontang LNG Plant | University of Manchester – LNG Trucker | TransGas LNG Tank Truck |
| **Facility Type** | Marine Transportation / Facility | Liquefaction / Export | Not reported | Land Transportation |
| **Accident** | Marine Incident | Methane Leak / Explosion | Methane Leak | Collision / Rollover / Fire |
| **Description** | • 1999: The vessel had a tail shaft problem and overheated bearing while at sea. There was no casualty or spillage experienced.<br>• 2009: The vessel was grounded on a coral reef habitat off the south coast of Puerto Rico near Guayanilla. No spillage or casualty was reported. | LNG leaked from an open run-down line during a pipe modification project, entering an underground concrete storm sewer system and underwent a rapid vapour expansion that overpressurized and ruptured the sewer pipes. | Limited information: LNG rolling, 150 t fossil gas exhaust | • 1993: trailer slid off third wheel just before entering highway. No fire, no product loss.<br>• 1994: trailer overturned when trying to negotiate a traffic circle at too high of speed. No product loss, no fire. Trailer emptied into second trailer without incident.<br>• 1998: trailer travelling at high speed was sideswiped by car then careened into a guardrail ripping open diesel fuel tanks. Ensuing diesel fuel fire trapped the driver in the cab where he died. Fire engulfed the LNG trailer until extinguished. No loss of product experienced. LNG partially transferred to the second trailer. Trailer then uprighted and sent to the transport yard to complete the transfer of product.<br>• 2003: trailer travelling too fast on a highway exit ramp overturned. There was no leakage of cargo from the overturned truck. The truck driver was slightly injured and received a speeding citation. Human / Operator error |
| **Cause** | • Mechanical / Material Failure<br>• Not reported | Human / Operator error | Human / Operator error | Multiple |
| **Impact** | Nothing reported | • Environmental impact: gas released<br>• Material damages: storm sewer system substantially damaged | Environmental impact: gas released | • Environmental impact: LNG leak and smoke<br>• Material damages: trailer damage |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Hongkai Liu et al. (2019). Research on Optimization of LNG pressure control safety accessories based on fault tree analysis. IOP Conf. Series: Earth and Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028 | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications |

| Date | 1995 | 1996 | 1996 | 1996 |
|---|---|---|---|---|
| **Location** | Not reported | Not reported | Not reported | United States |
| **Facility Name** | Mourad Didouche LNG Tanker | LNG tanker Finima | LNG tanker Portovenere | Subsea Pipeline in Tigert Pass, Louisiana |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility | Pipelines |
| **Accident** | Marine Incident | Other | Fire | Fire |
| **Description** | Lifting cable broke while the turbine was lifted out of the engine room, causing the turbine to fall from great height at the shipyard. | The vessel was boarded by pirates while anchored. The pirates stole paint and broached a lifeboat. There was no spillage or casualty. | Fire broke out in the engine room, when the empty vessel was at sea, which killed 6 people. There was no spillage of LNG. | A stern spud was dropped into the bottom of the channel in preparation for continued dredging operations. It struck and ruptured a fossil gas steel pipeline. The pressurised gas ignited upon reaching the surface and destroyed a dredge and a tug. 28 crew escaped into waters or nearby vessels. |
| **Cause** | Mechanical / Material failure | Other | Not reported | Human / Operator error |
| **Impact** | Material damages: turbine damage | Material damages: stolen paint and a lifeboat | Fatalities: 6 | • Environmental impact: gas released<br>• Material damages: dredge and tug destroyed |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. |

| Date | 1997 | 1997 | 1998 | 2000 |
|---|---|---|---|---|
| Location | Japan | Not reported | Not reported | United States |
| Facility Name | Northwest Swift LNG Tanker | LNG tanker Capricorn | LNG tanker Bonny | Southern LNG Facility, Georgia |
| Facility Type | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility | Regasification / Import |
| Accident | Marine Incident | Marine Incident | Other | Marine Incident |
| Description | The vessel collided with a fishing vessel about 400 km from Japan—some damage to the hull but no ingress of water. No LNG released. | Struck a mooring dolphin at a pier near the Senboku LNG Terminal in Japan. Some damage to the hull, but no ingress of water. No LNG released. | The LNG Tanker had complete power failure while at sea. There was no spillage or injuries / fatalities. | A 580-ft ship, the Sun Sapphire, lost control in the Savannah River and crashed into the LNG unloading pier at Elba Island. The facility experienced significant damage, and while it was undergoing reactivation, it had no LNG in the plant. |
| Cause | Not reported | Not reported | Mechanical / Material failure | Human / Operator error |
| Impact | Material damages: hull damage | Material damages: hull damage | Nothing reported | Material damages: Significant damage to LNG facility, including needing to replace 5 unloading arms; Sun Sapphire ship suffered 40-ft gash in hull. |
| Estimated Financial Loss | Not reported | Not reported | Not reported | Not reported |
| References | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications |

| Date | 2000 | 2000 / 2011 | 2001 / 2006 / 2017 / 2024 | 2003 |
|---|---|---|---|---|
| **Location** | Not reported | South Korea | Trinidad and Tobago | Not reported |
| **Facility Name** | LNG Jamal Tanker | HL Pyeongtaek LNG terminal | Atlantic Canada Facility in Trinidad | Hilli LNG Tanker |
| **Facility Type** | Marine Transportation / Facility | Regasification / Import | Land Transportation | Marine Transportation / Facility |
| **Accident** | Fire | Methane Leak | Explosion / Methane Leak<br>Fire | Other |
| **Description** | Insulating materials & vinyl sheeting burnt out during welding operations on the tank cover at the wharf. There was no spillage or casualty experienced. | • 2000: The LNG tank collided with a bulk earner at sea, and damage occurred to shell plating. No spillage was reported.<br>• 2011: During unloading a ship disconnected from the berth shortly after a scheduled overhaul of the unloading arms was completed and a very small leak of LNG was reported around the top of one emergency release coupler. | • 2001: Two men died working on building a tank as a part of an expansion of an Atlantic LNG plant after falling 80 ft from a scaffolding platform.<br>• 2006: A temporary eight inch isolation plug was blown from built-up pressure. The facility had been shut down due to the detection of a gas release from a two-inch pipeline. The release of fossil gas was brought under control, and personnel returned. While the company was carrying out repairs the plug blew, injuring one worker. It had been filled with inert gas to facilitate repairs.<br>• 2017: A fire at a power generation unit led to an evacuation of Atlantic's gas process facility in Point Fortin. A month prior there was an evacuation at the facility following a leak at one of its liquefaction units (trains).<br>• 2024: Employees were evacuated after a leak was discovered in one of the plant's tanks, temporarily releasing gas to the atmosphere. | The tanker had a boiler tube failure at anchorage. The failure did not result in any spillage or casualty. |
| **Cause** | Not reported | Not reported | Multiple | Not reported |
| **Impact** | Nothing reported | • Environmental impact: gas released<br>• Material damages: ship damage | • Fatalities: 2<br>• Injuries: 1<br>• Environmental impact: Gas released<br>• Material damages: isolation plug blew out | Nothing reported |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy.<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy.<br>• Trinidad Express (2017). Fire triggers evacuation at Atlantic LNG. Local News.<br>• Trinidad and Tobago Guardian (2024). Gas leak causes Atlantic LNG evacuation in Point. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| | | | | |
|---|---|---|---|---|
| **Date** | 2003 | 2003 | 2003 | 2003 |
| **Location** | Not reported | Not reported | Not reported | Not reported |
| **Facility Name** | Gimi LNG Tanker | Fuwairit LNG Tanker | Galicia Spirit LNG Tanker | LNG Century Tanker |
| **Facility Type** | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Not reported | Other | Other | Not reported |
| **Description** | The LNG tank touched the bottom when approaching the pier. It did not result in injuries or spillage. | It was grounded during the passage of typhoon "Maemi" while under construction. | Grounded after mooring ropes were released during the typhoon "Maemi" while under construction. The vessel sustained damage to the bottom and starboard shell plating. | Sustained main engine damage offshore. There was no LNG spillage or personnel injury / fatality. |
| **Cause** | Not reported | Weather and natural conditions | Weather and natural conditions | Mechanical / Material failure |
| **Impact** | Nothing reported | Nothing reported | Material damages: bottom of vessel and starboard shell plating | Nothing reported |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| Date | 2003 | 2003 / 2015 / 2016 | 2004 | 2004 |
|---|---|---|---|---|
| **Location** | Not reported | France | Korea | Not reported |
| **Facility Name** | LNG tanker Berge Arzew | Dunkirk LNG Terminal (For-Sur-Mer) | Tenaga Lima LNG Tanker | British Trader LNG Tanker |
| **Facility Type** | Marine Transportation / Facility | Regasification / Import | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Other | Fire / Explosion<br>Marine Incident / Other | Marine Incident | Fire |
| **Description** | While under construction, mooring ropes broke due to typhoon "Maemi" and drifted away from the berth, touching the bottom. The bottom plating was damaged. | • 2003: An explosion occurred while unloading a ship at a methane tanker terminal that contained 3 tanks connected to a flare network. 4,000 N-m³/hour, were discharged into the atmosphere while awaiting repairs (requiring some 20 hours)<br>• 2015: Employee found dead at the unloading docks of an LNG terminal. Death would be linked to a fall.<br>• 2016: LNG passed into a flare stack circuit causing vapours to ignite at the base of the flare stack. Estimated that 1,000 cubic metres of LNG was released during the event. | The vessel had fishing lines foul her propeller shaft seal on departure in ballast from Korea and contacted underwater rocks after deviating to effect repairs. The starboard side shell plating in the No. 1 membrane tank was heavily damaged, but minimal damage to the inner hull. No spillage or casualties were experienced. | A minor electrical fire onboard damaged one transformer while the vessel was at sea |
| **Cause** | Weather and natural conditions | Human / Operator error<br>Mechanical / Material failure<br>Other | Other | Not reported |
| **Impact** | Material damages: bottom plating damaged | • Fatalities: 1 (2015)<br>• Environmental impact: 1,000 m³ (500 t) of LNG released (2016); gas leak (4,000 N-m³/hour for 20 hours)<br>• Material damages: control room physical damage (broken window panes, dust and debris inside the room) (2003) | Material damages: extensive damage to outer hull | Material damages: transformer damaged |
| **Estimated Financial Loss** | Not reported | € 10,000,000 (2016) | Not reported | Not reported |
| **References** | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • ARIA & FR government (nd). Inhibition of alarms in an LNG terminal (48392).<br>• ARIA & FR government (nd). Explosion inside the terminal's flare (25619).<br>• ARIA & FR government (nd). Death of an employee in LNG terminal (47287). | • Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2. Available at: Oil and HNS Spill Plan<br>• Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| Date | 2004 | 2005 | 2005 | 2005 |
| --- | --- | --- | --- | --- |
| Location | Algeria | Not reported | Not reported | Not reported |
| Facility Name | Algerian LNG Plant | Methane Kari Elin LNG tanker | Hispania Spirit LNG Tanker | Laieta LNG Tanker |
| Facility Type | Liquefaction / Export | Marine Transportation / Facility | Marine Transportation / Facility | Marine Transportation / Facility |
| Accident | Explosion / Fire | Other | Marine Incident | Other |
| Description | LNG production plant steam boiler exploded, triggering a second, more massive, vapour-cloud explosion and fire. | Suffered damaged insulation and had a nitrogen leak. No LNG spillage. | The hull was damaged via contact during berthing operations, which resulted in oil spill. There was no LNG spill. | The engine broke down while in ballast. |
| Cause | Mechanical / Material failure | Not reported | Not reported | Mechanical / Material failure |
| Impact | • Fatalities: 27<br>• Injuries: 56-72<br>• Environmental: 3,000 – 4,000 kg of methane equivalent estimated, with leakage higher due to dispersion<br>• Material damage: 3 liquefaction trains, buildings, and outside the plant boundaries | Environmental impact: nitrogen leak | Environmental impact: oil spill | Not reported |
| Estimated Financial Loss | $900,000,000 | Not reported | Not reported | Not reported |
| References | • Algerian LNG Plant Explosion Fact Sheet prepared by California Energy Commission Staff. Revised April 20, 2004<br>• Ouddai, R., Chabane, H., Boughaba, A. and Frah, M. (2012) 'The Skikda LNG accident: losses, lessons learned and safety climate assessment', Int. J. Global Energy Issues, Vol. 35, No. 6, pp.518–533.<br>• City of Hyattsville by CH IV International – The LNG Specialists _Statement of Qualifications | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. |

| Date | 2006 | 2006 / 2008 | 2007 | 2009 |
|---|---|---|---|---|
| **Location** | United States | Not reported and Puerto Rico | China | United Kingdom |
| **Facility Name** | Subsea Pipeline in Louisiana | Catalunya Spirit LNG Tanker | Shanghai China (facility name not disclosed | South Hook LNG Terminal |
| **Facility Type** | Pipelines | Marine Transportation / Facility | Not reported | Regasification / Import |
| **Accident** | Other<br>Fire | Not reported / Marine Incident | Explosion | Methane Leak |
| **Description** | A ruptured high-pressure fossil gas pipeline was struck by a 5-ton mooring spud dropped from a towing vessel. The released gas ignited, and subsequent fire engulfed the towing vessel and two barges. 5 out of 8 people onboard were killed and 1 reported missing. | • 2006: The vessel's insulation was damaged. No LNG spillage.<br>• 2008: The vessel went adrift for hours off Cape Cod because a computer glitch caused the vessel to lose power.. | Limited information: One person died and 16 others were injured in an explosion caused<br>by tank pressure test | A maximum of 10 litres of LNG was spilled and "immediately vapourised" because of the unintended activation of the emergency shutdown system, which caused powered emergency release couplings to separate, discharging LNG. |
| **Cause** | Human / Operator error | • Not reported<br>• Mechanical / Material failure | Human / Operator error | Not reported |
| **Impact** | • Fatalities: 5<br>• Missing: 1<br>• Environmental impact: Gas released<br>• Material damages: Fire engulfed towing vessel and two barges | Material damages: insulation damage | • Fatalities: 1<br>• Injuries: 16<br>• Environmental impact: gas released | Environmental impact: Gas released |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Environmental Resources Management (2018). Annex 5C – Summary of Industry Incidents Review. Hong Kong. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | Hongkai Liu et al. (2019). Research on Optimization of LNG pressure control safety accessories based on fault tree analysis. IOP Conf. Series: Earth and Environmental Science. 295 (2019) 032028. DOI:10.1088/1755-1315/295/3/032028 | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy.<br>• Western Telegraph. (2009) Health and Safety Executive confirms Milford Haven South Hook LNG spill. |

| **Date** | 2010 | 2010 | 2010 / 2016 / 2017 / 2019 | 2011 |
|---|---|---|---|---|
| **Location** | Australia | Not reported | France | Taiwan |
| **Facility Name** | Withnell Bay LNG Facility | Umm Al Amad LNG tanker | Montoir de Bretagne LNG Terminal | Yung An LNG Terminal |
| **Facility Type** | Storage / Liquefaction | Marine Transportation / Facility | Regasification / Import | Regasification / Import |
| **Accident** | Methane Leak / Fire | Other | Methane Leak | Methane Leak |
| **Description** | During loading, a ship suffered cryogenic burns when 2,000-4,000 litres of LNG were spilled. | Six pirates boarded the vessel while it was sailing. The pirates stole cash from the ship and crew members. | • 2010: Liquid passed into the gas take-off line during discharge operations.<br>• 2016: A pipe supplying a foam generator broke during a manual purging operation of an LNG network.<br>• 2017: Following a 1-week shutdown, an LNG terminal being restarted began leaking after a high-pressure pump was turned on, forming a cloud of flammable gas.<br>• 2019: An LNG leak occurred in an LNG terminal at a pier, with an estimated 26,000 cubic metres of LNG released into the atmosphere, which created a cloud of fossil gas that drifted towards the terminal. Not reported | Limited information about the incident. The vessels' master decided to suspend discharge and move the ship off the berth. Problems were rectified and the vessel returned to complete cargo discharge |
| **Cause** | Not reported | Other | Human / Operator error<br>Mechanical / Material Failure | Not reported |
| **Impact** | • Environmental impact: Gas leakage<br>• Material damages: burn of the ship | Material damages: cash stolen from crew members | • Environmental impact: gas released; LNG released (26,000 cubic metres during 2019; again in 2017); gas released in 2016<br>• Material damages: damage to ship unloading in the terminal (part of it's manifold and feed lines) | • Environmental impact: Gas released<br>• Material damages: ship damage |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy. | Nwaoha, T. C. (2011). Advanced Risk and Maintenance Modelling in LNG Carrier Operations. PhD Thesis submitted to Liverpool John Moores University. | • Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy.<br>• ARIA & FR government (nd). Natural gas leak in an LNG terminal (53094).<br>• ARIA & FR government (nd). Gas leak in an LNG terminal (50755).<br>• ARIA & FR government (nd). Failure of the fire suppression network in an LNG terminal (48644).<br>• Bajic, A. (2021) Leak at Montoir-de-Bretagne LNG terminal halts send-out. Offshore Energy. | Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy. |

| Date | 2012 | 2014 | 2015 | 2017 |
|---|---|---|---|---|
| **Location** | Venezuela | United States | North Sea | Not reported |
| **Facility Name** | Amuay refinery in Punto Fijo | Plymouth-LNG Peak Shaving Plant | Al Oraiq LNG Tanker | Al Khattiya LNG Tanker |
| **Facility Type** | Liquefaction / Export | Storage / Liquefaction | Marine Transportation / Facility | Marine Transportation / Facility |
| **Accident** | Methane Leak / Fire<br>Explosion | Explosion | Marine Incident | Marine Incident<br>Collision / Rollover |
| **Description** | In 2012, an undetected leak at Venezuela's largest oil and LNG refinery experienced a vapour cloud explosion. When it ignited, it set off a catastrophic blast that killed 47-100 people, injured over 100 people, and destroyed or damaged 1500-3000 surrounding homes and buildings. It took firefighters four days to put out the blaze. | A fuel / air mixture remained in the system following maintenance, which auto-ignited upon system startup, causing an internal detonation that resulted in rapid overpressure and subsequent failure of portions of an LNG purification and regeneration system. | LNG carrier Al Oraiq collided with bulk carrier Flinterstar off Zeebrugge (Belgium) in a busy shipping area at the crossroads of the North Sea traffic separation schemes and the access channels to the ports of Zeebrugge and Antwerp. The LNG carrier entered the port of Zeebrugge for inspection, and the damaged bulk carrier grounded and sank 5.3 nm from the coast. It was carrying 3,000 tonnes of steel, 430 tonnes of heavy fuel oil (IFO 380), and 115 tonnes of diesel in its bunker tanks. | Al Khattiya, an LNG carrier, had two ballast tanks breached with the loss of some ballast water after an oil tanker hit the ship in February 2017. Cargo tank pressures were stable, and there was no loss of LNG from the cargo tanks. |
| **Cause** | Human / Operator error<br>Mechanical / Material failure | Human / Operator error | Human / Operator error | Not reported |
| **Impact** | • Fatalities: 47 - 100<br>• Injuries: 100+<br>• Environmental impact: gas leakage<br>• Material damages: 1600-3000 homes and buildings completely damaged, 200 people evacuated | • Fatalities: 0<br>• Injuries: 56<br>• Environmental: LNG released in spray and vapourized for approx. 25 hours, estimated at 9.3 barrels per hour or approx. 234 barrels released<br>• Material damages: Plant facilities, railroad tracks outside the plant grounds, and surrounding town and communities evacuated within 2-mile radius | • Injuries: 1<br>• Environmental impact: potential release of chemicals and spill of heavy fuel oil and diesel<br>• Material damages: bulk carrier ground and sank | Nothing reported |
| **Estimated Financial Loss** | Not reported | $45,749,300 | Not reported | Not reported |
| **References** | • Mishra et al. 2014 - Amuay refinery disaster: The aftermaths and challenges ahead<br>• CNN 2024 - Natural gas exports have lax oversight that exports say could lead to a devastating explosion – its happened before | DOT, PHMSA, OPS, WUTC. Failure Investigation Report – LNG Peak Shaving Plant, Plymouth, Washington. (2016). | • Cedre. Flinterstar_Al Oraiq<br>• Major LNG Accidents. Draft Environmental Impact Assessment for the Port Delfin LNG Project Deepwater Port Application. US Department of Energy. | Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2. Available at: Oil and HNS Spill Plan |

| Date | 2018 | 2019 | 2020 | 2020 |
|---|---|---|---|---|
| **Location** | United States | United Arab Emirates | France | China |
| **Facility Name** | Cheniere Energy's Sabine Pass LNG terminal | ASEEM LNG Carrier | The Fos Cavaou LNG Terminal | LNG Tanker Truck in China |
| **Facility Type** | Liquefaction / Export | Marine Transportation / Facility | Regasification / Import | Land Transportation |
| **Accident** | Methane Leak | Marine Incident Collision / Rollover | Fire | Explosion |
| **Description** | Two LNG tanks were shut down after leaks were found, including 14 gas leaks and four cracks in a tank's outer shell. The -260°F LNG caused brittleness in the outer tank, which isn't designed for such temperatures. A history of safety issues dating back to 2008 was revealed, leading federal regulators to mandate corrective actions before restarting. Despite concerns about transparency, the case was settled in 2018 without litigation | The ship collided with a VLCC in the passage channel of the Fujairah anchorage area, UAE, 2019. The hulls of both vessels were breached below the waterline; the VLCC sustained extensive damage. No LNG was released. | During a storm, the vent of an LNG storage tank relief valve caught fire at an LNG terminal. The fire was caused from a loss of valve tightness and an unidentified ignition source. | A tanker truck carrying liquefied gas exploded on a highway, with debris and plumes of smoke engulfing the highway and damaging buildings. A second explosion occurred after the damaged truck was propelled into a factory building. 19 people were killed and over 170 injured. |
| **Cause** | Human / Operator error | Human / Operator error | Not reported | Not reported |
| **Impact** | Environmental impact: gas / methane leaks | Material damages: extensive damage to vessels involved in collision | Material damages: Not reported | • Fatalities: 19<br>• Injuries: 170 +<br>• Material damages: buildings |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | CHPNY, PSR, & PSR (2023). Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking and Associated Gas and Oil Infrastructure | Shannon Technology and Energy Park. (2021) Environmental Impact Assessment Report. Appendix 2. Available at: Oil and HNS Spill Plan | ARIA & FR government (nd). Fire from a reflief valves vent at an LNG Terminal (57889). | BBC (2020). China explosion: Tanker truck blows up, killing 19 people. |

| Date | 2022 | 2023 | 2023 | 2024 |
|---|---|---|---|---|
| **Location** | United States | Taiwan | Australia | Australia |
| **Facility Name** | Freeport LNG terminal | Taichung LNG Terminal | Pluto LNG Plant | HL Eco LNG tanker |
| **Facility Type** | Liquefaction / Export | Regasification / Import | Liquefaction / Export | out of scope) Direct Use |
| **Accident** | Explosion / Fire | Not reported | Explosion | Marine Incident |
| **Description** | Methane was ignited due to severely damaged electrical wiring in the pipe rack, which led to a vapour cloud explosion and a small secondary pool fire on the northeast end of the pipe rack in the elevated LNG drainage trench. The cause of the incident was a blocked relief valve, leading to a "low order" overpressure in an 18-in. recirculation line. | Limited information: The operations of the LNG receiving terminal had technical glitches. Technical problems with the terminal's safety instrumented system lead to a suspension of fossil gas output from the facility and subsequent decline in power supply from the power plant that generates electricity using fossil gas from the terminal. | An explosion occurred in the flare tower. Routine maintenance was being carried out at the time of the event, and the facility was not producing LNG, condensate, or pipeline gas. | While trying to anchor, an LNG tanker had an issue with its propulsion system and lost control, causing it to drift and collide with an anchored bulk carrier. Damage was so extensive that parts of the tank were found in the other ship. Both vessels were in ballast, so no immediate danger of pollution. |
| **Cause** | Human / Operator error | Not reported | Not reported | Human / Operator error |
| **Impact** | Material damages: small damage around the pipe | Compromised electricity supply | Material damages: Not reported | Material damages: vessels damaged |
| **Estimated Financial Loss** | Not reported | Not reported | Not reported | Not reported |
| **References** | • IFO Group Safety, Risk & Fire Consultant. (nd) Case Study: Freeport LNG Incident.<br>• US DOT (nd). Freeport LNG Incident and Regulatory Response.<br>• Reuters (2022). U. S. regulator releases report blaming Freeport LNG blast on inadequate processes. | Taipei Times (2023). Glitch at Taichung LNG terminal halts operations. | LNG Prime (2023) Australias Woodside investigating Pluto LNG incident. | • Raza, R. (2024). Update- LNG Bunker tank of vessel sliced open in violent collision. Marine Traffic.<br>• Wingrove, M. (2024). Video- LNG-capable bulker collision raises questions on LNG tank location. Riviera. |

**Table A2: Summary of established and updated protocols listed in chronological order.**

| Year | Event | Name |
|---|---|---|
| 1962 | Protocol established | IEC 60079 |
| 1974 | Agency established | IEA |
| 1978 | Agency established | SIGTTO |
| 1982 | Agency granted IMO status | SIGTTO |
| 1982 | Protocol established | EU Seveso Directive |
| 1986 | Agency established | OISD |
| 1986 | Protocol established | IMO – IGC Code |
| 1988 | Protocol established | WHMIS |
| 1993 | Protocol established | Canadian NPRI (updated annually) |
| 2007 | Protocol established | World Bank – Environmental, Health, and Safety Guidelines |
| 2007 | Protocol amended | OSHS 1910.110 |
| 2009 | Protocol established | US Coast Guard and US Homeland Security – LGCNCOE (periodic updates since establishment) |
| 2010 | Protocol established | ISO 28460 |
| 2012 | Protocol last updated | JGA-107-RPIS, 2012 |
| 2012 | Protocol last updated | JGA-108-RPAS, 2012 |
| 2012 | Protocol last updated | EU Seveso Directive |
| 2013 | Protocol established | API (including API 620 and API RP 752) |
| 2015 | Protocol last updated | JGA-102, 2015 |
| 2015 | Protocol updated | WHMIS |
| 2015 | Protocol established | CSA SPE-276.1:20 |
| 2015 | Protocol established | ISO 16903 |
| 2015 | Protocol established | ISO 16901 |
| 2016 | LNG Exports Start | US Exports of LNG |
| 2016 | Protocol last updated | OSISD Standard 194 |
| 2016 | Protocol established | EMSA EN 1473 |

| Year | Event | Name |
|---|---|---|
| 2016 | Protocol last amended | IMO – IGC Code |
| 2017 | Protocol last updated | JGA-103, 2017 |
| 2017 | Protocol established | SGMF – Bunkering safety guidelines |
| 2017 | Protocol established | ISO 20159 |
| 2017 | Protocol established | IACS Rec 142 |
| 2018 | Protocol established | CSA Z276:22 |
| 2019 | Protocol established | GIIGNL Guidelines |
| 2021 | Protocol last updated | EMSA EN 1473 |
| 2021 | Agency established | API refers to the CLNG for information and standards |
| 2021 | Protocol last updated | API (including API 620 and API RP 752) |
| 2021 | Protocol last reviewed | ISO 16903 |
| 2021 | Protocol last reviewed | ISO 28460 |
| 2021 | Protocol last reviewed | ISO 20159 |
| 2022 | Protocol last updated | SGMF – Bunkering safety guidelines |
| 2022 | Protocol last updated | CSA Z276:22 |
| 2022 | Protocol last updated | CSA SPE-276.1:20 |
| 2022 | Protocol last updated | ISO 16901 |
| 2023 | Protocol established | NFPA 59A |
| 2023 | Protocol last updated | IEC 60079 |
| 2023 | Protocol last updated | NFPA 59A |
| 2024 | Protocol published | SIGTTO – Gas as Fuel on Gas Carriers – Review of Practice |
| 2024 | Protocol last updated | Canadian NPRI (updated annually) |
| 2024 | Protocol last amended | IMO – IGF |

greenpeace.de