Security & safety issues implementation

Security & safety issues implementation and assessment according to pre – EU regulation procedures

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Revision History

<table>
<thead>
<tr>
<th>Rev</th>
<th>Date</th>
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</thead>
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</tr>
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<td>Final review</td>
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<td>EIHP</td>
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</table>

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This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.
Executive Summary

The LNG Blue Corridors project’s aim is to establish LNG as a real alternative for medium and long distance transport, first as a complementary fuel and later as an adequate substitute for diesel.

During the project several deliverables are being made, according to the LNG issues as fuel for Heavy Duty vehicles. In this deliverables are shown the actual situation of this fuel in the sector and the future and also the LNG Blue Corridors recommendations, which shown how the project is going to proceed in these matters that are not yet sufficiently evolved in relation with the standards and regulations, safety and security, fuel quality, etc.

In this report it has wanted to show how the safety and security of LNG as fuel is dealt in the actuality. It has studied the LNG properties and all the possible hazards, how it is studied and analyzed the measures to ensure the LNG station as safety and security and the recommendations of the procedures to ensure that the stations, in the future and actuality, are being safety and security.

Like any fuel, safe handling procedures and proper safety precautions must be followed when working with LNG. Many years of experience using natural gas vehicles have proven that natural gas can be used safely as a fuel for vehicles. However, using LNG, or any other alternative fuel, involves different safety procedures than most fuel providers and consumers are accustomed to following.

In this report it is shown the safety considerations for LNG fuelling stations, general properties affecting fire hazards, fire hazards during transport, transfer to storage tanks, storage and others.

An assessment of relative safety in the LNG transport fuel supply chain is accompanied by an accurate safety assessment of vehicle transportation and related safety risks.

Also it is shown a safety analysis and comparison to other transport fuels, which is based on safety assessment of bulk delivery and fuel storage at fuelling stations and of vehicle fuel storage tanks.

An overview of general safety information for LNG stations, driver training, and training of LNG station staff emergency responders also is described in the report.

Also it is described the security and safety implementation issues according to pre – EU regulation procedures and other regions, in a way that it is shown the lack of the actual regulations in these issues and how other countries as US, which have more evolved on the LNG fuel issues deal these themes.

The LNG industry has taken many steps over the years to develop technology and implement protocols for the safe use, transport, and dispensing of this fuel.

Currently, and due to the fact that LNG technology for vehicles is still taking off in Europe, there is a lack of technical legislation on the subject. However, standardisation bodies such as UNECE and ISO are currently working on solving standardisation issues.

There are very few countries with an integral regulation on the building and operation of LNG stations. It is common that such regulation will develop when a country has one or more stations in operation.
Contents

Executive Summary ................................................................................................................................. 3
1  Introduction ...................................................................................................................................... 7
   1.1  LNG Blue Corridors project .................................................................................................. 7
   1.2  Aim of this deliverable ......................................................................................................... 8
2  Physical properties ............................................................................................................................ 11
3  LNG supply and fuelling infrastructure .......................................................................................... 15
4  Analysis and security measures ....................................................................................................... 16
   4.1  Hazard and Operability study methodology .................................................................... 18
   4.2  Sequence of examination .................................................................................................... 18
   4.3  Details of study procedure ................................................................................................. 19
   4.4  HAZOP effectiveness .......................................................................................................... 20
   4.5  Non-traditional HAZOP equivalents ................................................................................. 22
      4.5.1  Computer HAZOP (CHAZOP) ................................................................................... 22
      4.5.2  FMEA ....................................................................................................................... 23
      4.5.3  Other ......................................................................................................................... 23
5  General safety, operation and maintenance of LNG stations ....................................................... 24
   5.1  Fire .......................................................................................................................................... 25
      5.1.1  Flash fire: ...................................................................................................................... 25
      5.1.2  Jet fire ......................................................................................................................... 26
   5.2  Pool and brittle failure ............................................................................................................ 26
      5.2.1  Brittle fracture and cryogenic burns ........................................................................... 27
   5.3  Phase change and overpressure considerations ..................................................................... 27
      5.3.1  Container overpressure failure .................................................................................... 27
      5.3.2  Rapid phase transition (RPT) ...................................................................................... 28
      5.3.3  Boling liquid expanding vapour explosion (BLEVE) .................................................... 28
      5.3.4  Vapour cloud explosion (VCE) .................................................................................... 29
      5.3.5  Vapour cloud ignition ................................................................................................. 29
      5.3.6  Trapped LNG ............................................................................................................... 30
   5.4  Cryogenic burns/frostbite ........................................................................................................ 30
   5.5  Environmental effects ............................................................................................................ 30
5.5.1 Asphyxia

5.6 Earthquakes and terrorism

5.7 Safety considerations for LNG fuelling stations

5.7.1 General properties affecting fire hazards

5.7.2 Fire hazards during transport

5.7.3 Fire hazards due to storage tanks

5.7.4 Fire hazards during storage

5.7.5 Other hazards

5.8 General safety information for LNG stations

5.8.1 Driver training

5.8.2 Training of LNG station staff

5.8.3 Recommendations for training staff

5.8.4 Emergency responders

6 Safety conditions to the LNG Value Chain

7 Assessment of relative safety in the LNG transport fuel supply chain

7.1 Safety assessment of vehicle transportation

7.1.1 Safety risks

7.1.2 Safety analysis and comparison to other transport fuels

7.2 Safety assessment of bulk delivery and fuel storage at fuelling stations

7.2.1 Safety analysis and comparison to other fuels

7.3 Safety assessment of vehicle fuel storage tanks

7.3.1 Mitigating technologies, codes and standards

7.3.2 Safety analysis and comparison to other fuels

8 Guidelines and standards for refuelling

8.1 Spain

8.2 The United Kingdom

8.3 The Netherlands

8.4 Sweden

8.5 Portugal

8.6 Other European countries

9 EU regulatory framework
9.2 End user experiences

9.2.1 Spain

9.2.2 The United Kingdom

9.2.3 The Netherlands

9.2.4 Sweden

9.2.5 Portugal

10 Conclusion

11 Recommendations

List of Tables

List of figures
1 Introduction

1.1 LNG Blue Corridors project

The LNG Blue Corridors project’s aim is to establish LNG as a real alternative for medium- and long-distance transport—first as a complementary fuel and later as an adequate substitute for diesel. Up to now the common use of gas as fuel has been for heavy vehicles running on natural gas (NG) only for municipal use, such as urban buses and garbage collection trucks. In both types of application, engine performance and autonomy are good with present technologies, as they are well adapted to this alternative cleaner fuel.

However, analyzing the consumption data, the equivalence in autonomy of 1 liter of diesel oil is 5 liters of CNG (Compressed Natural Gas), compressed to 200 bar. Five times more volume of fuel prevents the use of CNG in heavy road transport, because its volume and weight would be too great for a long-distance truck. This opens the way for LNG (Liquefied Natural Gas), which is the way natural gas is transported by ship to any point of the globe. NG liquefies at 162º C below zero, and the cost in energy is only 5% of the original gas. This state of NG gives LNG the advantage of very high energy content. Only 1,8 liters of LNG are needed to meet the equivalent autonomy of using 1 liter of diesel oil. A 40-ton road tractor in Europe needs a tank of 400 to 500 liters for a 1,000 km trip; its equivalent volume with liquid gas would be 700 to 900 liters of LNG, a tank dimension that could easily be fitted to the side of the truck chassis. LNG therefore opens the way to the use of NG for medium- and long-distance road transport.

LNG has huge potential for contributing to achieving Europe’s policy objectives, such as the Commission’s targets for greenhouse gas reduction, air quality targets, while at the same time reducing dependency on crude oil and guaranteeing supply security. Natural gas heavy-duty vehicles already comply with Euro V emission standards and have enormous potential to reach future Euro VI emission standards, some without complex exhaust gas after-treatment technologies, which have increased procurement and maintenance costs.

To meet the objectives, a series of LNG refueling points have been defined along the four corridors covering the Atlantic area (green line), the Mediterranean region (red line) and connecting Europe’s South with the North (blue line) and its West and East (yellow line) accordingly. In order to implement a sustainable transport network for Europe, the project has set the goal to build approximately 14 new LNG stations, both permanent and mobile, on critical locations along the Blue Corridors whilst building up a fleet of approximately 100 Heavy-Duty Vehicles powered by LNG.

This European project is financed by the Seventh Framework Programme (FP7), with the amount of 7.96 M€ (total investments amounting to 14.33 M€), involving 27 partners from 11 countries.

This document corresponds to the 12th deliverable within work package 3. It is a document describing security & safety issues implementation and assessment according to pre-EU regulation procedures. This document will be available at the project website: http://www.lngbluecorridors.eu/.
1.2 Aim of this deliverable

Liquefied Natural Gas (LNG) is one of the emerging fuels in Europe. LNG is attractive as a motor fuel for different modes of transport, such as for road vehicles, boats and rail dependent vehicles. Natural gas and primarily LNG play a crucial part in improving the local air quality and the transition to more sustainable mobility. The construction of an LNG infrastructure lays the basis for driving and running on LNG and liquefied biomethane (LBM).

As it is explained in following sections in more extensive form, as with any fuel, LNG poses a number of potential hazards to health and property. Some of these are common to any transport fuel, such as combustion, while others are unique to LNG, such as cryogenic burns.

The following hazards listed are some important items about safety and security issues described in this deliverable.

- Jet fire
- Explosion
- Asphyxia
- Brittle failure and cryogenic burns
- Trapped LNG
- Vapour clouds
- BLEVE
- Earthquakes and terrorism
- Etc.

Besides a description of potential Hazards, it is shown how it must be mitigate and avoided these hazards. After that, there is a detailed assessment about safety in the LNG transport fuel supply chain with a comparison with other fuels. This comparison focus in the intention to shown that all fuels have a hazards and the LNG isn’t a special case, showing which cases the LNG fuel it should be taken care.

Another topic, which is described in this deliverable in order to complete with the explication of how the LNG fuel must be treated, is the training staff. In the final chapters it is shown a summary of a training to take into account to ensure that all the staff and persons related with this fuel have the correct information about the security and safety issues.

The LNG production plants and terminals have a set of requirements defined for production and storage of the fuel. However the storage at small LNG stations and the regulations for building LNG service stations are not always covered in legal text and requirements. As is shown in section number 5, EU regulation framework, the existing regulations are still continuously updated.

In common with most industries LNG transportation is subject to a myriad of international, regional and national standards and procedures. The generalised hierarchy of regulations is shown in the following figure – all of these elements impact on NGV sector.

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1 The Oxford Institute for Energy Studies; The Prospects for Natural Gas as a Transport Fuel in Europe, March, 2014
Currently, the two standards that are most developed are PGS 33: Natural Gas: installations for the supply of Liquefied Natural Gas (LNG) to motor vehicles and ISO Draft International Standard 16924, Status 02/2014: Enquire Stage.

PGS 33 is a Dutch guideline for LNG stations. PGS 33 is part of the PGS publications, which serve as guidelines for companies that produce, store, transport or use dangerous goods. Other PGS publications deal with e.g. LPG or CNG. PGS publications will also serve as a basis for the permitting of dangerous facilities. The PGS publications are set up by a team of representatives of both the authorities and the industry.

PGS33-1 is focussed on LNG stations for motor vehicles. PGS33-2 will be the directive for LNG bunkering stations for marine applications. This standard is under development.

The recommendations in the PGS 33 are not absolute, and it is possible to propose alternative solutions, provided they guarantee similar results.

Under the NEN secretary, an ISO norm (16924) is being developed regarding LNG stations for fuelling vehicles. The norm is still in draft status, and is expected to be finalized and published in 2016.

This norm is voluntary, but it is probable that it will be adopted by several countries as part of the regulatory framework, or will be referred to in legislation for which they serve as the technical basis. This explains the importance and general interest in the development of this standard.
The standard has been prepared since 2010 by a committee of industry representatives from all over the world that have met during 8 multi-day meetings in Amsterdam, Mumbai, Milan, Vancouver, Hessingue, Decin, The Hague and Rotterdam.

The draft version of the standard is currently shared with all the national members that are asked to comment. The process is based on consensus. If this consensus is reached, the final draft will be sent to all ISO members for final vote.

The scope is the design, construction, operation, maintenance and inspection of stations for fuelling LNG to vehicles. The CNG equipment is covered in DIS 16923\(^2\)\(^3\).

The issues explained above are shown in more detail in following sections with the intention of study the actual and the future state, the progress, of the safety issues related with the LNG refuelling stations and their value chain.

Also in final sections of the document it can see the conclusions of the study and the recommendations of the LNG Blue Corridors, with the aim of being able to equate the safety them with other fuels, especially in terms of regulation.

The Deliverable is structured in the following sections:

- Physical properties: Where it is described the properties of the LNG fuel which affects to the Hazards issues.
- LNG supply and fuelling infrastructure: It is shown the distribution in the value chain of LNG.
- Analysis and security measures: It is describe the operation before and after the construction of the LNG fuel in security and safety issues.
- General safety, operation and maintenance of LNG stations
- Safety conditions to the LNG value chain
- Safety considerations for LNG use in transportation
- Assessment of relative safety in the LNG transport fuel supply chain
- Guidelines and standards for refuelling
- EU regulatory framework
- Conclusion
- LNG blue corridors project recommendations

\(^2\) Natural gas—liquefied natural gas (LNG) delivery installations for vehicles; Hazardous Substances Publication Series 33-1:2013

\(^3\) ISO/DIS 16924, Natural gas fuelling stations — LNG stations for fuelling vehicles, 2013
2 Physical properties

In deliverables before, the properties of the LNG have been already explained, but in relation with the safety themes, the properties of the LNG are a crucial topic to take into account, for this reason in this section will explain which is the most relevant physical properties and how, these properties, affect to the safety issues.

The main properties which it is necessary control are below:

Methane content

Lng can contain a higher percentage of methane gas when is vaporized that the natural gas, because the composition of both is slightly different, since compounds such as H2O and CO2 are removed before the finalization of the liquefaction process.

In this way, when the LNG is stored for long periods, compared to other hydrocarbons, the methane’s lower boiling temperature makes the methane portion decrease because the methane boils into the vapour phase in the storage tank, this means that the disuse of the LNG its composition can change (“weatherization” or “enrichment” for more detailed information related to this matter see deliverable 3.2 “fuel quality”).

Odourless and colourless

LNG fuel is odouless, non-toxic and non-corrosive. When it is exposed to the environment or spilled, it is, rapidly and completely evaporate leaving no residue in water or soil. When vaporization occurs, the gas becomes lighter than air and begins to rise.

Due to the colourless and odourless nature of LNG vapours, electronic methane gas detector are used to identify the presence of natural gas. These detectors can identify concentrations of gas well below the level needed to combust, additionally, due to the cold nature of LNG vapours, air moisture will condence into a visible cloud in the presence of an LNG spill.

Asphyxiant

LNG is non-toxic but it is an asphyxiant when concentrated in sufficient quantities, in this way it is important to highlight that the LNG cannot be detected through the sense of smell. It is necessary take into account that the LNG evaporates at at -162.22 °C (at atmospheric pressure) and forms a visible cloud, due to the condensation of moisture in the air, which is initially heavier than air until gas temperatures rise above -160.67 °C at which point natural gas becomes lighter than air and dissipates. If LNG is in contact with water, being lighter than water, boils on top until it evaporates.

Flammability limits

Natural gas burns with a visible flame. Natural gas has narrow flammability limits, combusting when in air/flow proportions of 5 – 15 %. Below 5% the mix is too lean to burn and above 15% the mix is too rich to burn. Pools of liquefied natural gas do not ignite as readily as pools of gasoline or diesel fuel.
Methane gas’s autoignition temperature is 540 °C significantly higher than gasoline (257.22 °C) or diesel (315.56 °C). As such, open flames and sparks can ignite natural gas; however, many hot surfaces such as a car muffler will not. The flame front on burning methane in an open environment has a very slow flame speed of about 6.44 km/h. Following, shown the flammability limits and how it is produced.

![LNG flammability range](image)

Below a table with a summary of the safety and environmental implications of the LNG properties is shown:

<table>
<thead>
<tr>
<th>Property</th>
<th>Consequence</th>
</tr>
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<tbody>
<tr>
<td>LNG is a cryogenic liquid.</td>
<td>Direct contact with skin causes freezer burns. Exposure of sufficient duration can embrittle carbon steel.</td>
</tr>
<tr>
<td>LNG evaporates completely and cleanly without a residue.</td>
<td>An LNG spill leaves minimal environmental impact (freezing effects only).</td>
</tr>
<tr>
<td>LNG evaporates rapidly from ground or water contact.</td>
<td>Vapour plume is the main hazard from spills. It can ignite, then fire is the main hazard.</td>
</tr>
<tr>
<td>The liquid density of LNG is low, less than half of that of water.</td>
<td>LNG tankers float high in the water. A large tank of LNG, say 30 m high, would have a liquid head of around 1.3 atmospheres. This is a comparatively low pressure to pump against.</td>
</tr>
<tr>
<td>The expansion factor in going from liquid at the boiling point to vapour at standard</td>
<td>This density difference provides for the economical</td>
</tr>
<tr>
<td>Ambient temperature is around 600 (594 - 625).</td>
<td>Transport and storage of natural gas as a liquid.</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>The molecular weight of natural gas is less than that of air (specific gravity of 0.60 – 0.68).</td>
<td>The low molecular weight of LNG vapour makes it lighter than air at ambient temperature. Natural gas rises and poses a lower threat than most hydrocarbon vapours, including gasoline, that are heavier than air.</td>
</tr>
<tr>
<td>A boiling pool produces cold vapours (at the normal boiling point).</td>
<td>LNG vapours at their boiling point are significantly heavier than air, by about a factor of 1.5.</td>
</tr>
<tr>
<td>Water condensation in plume creates a visible cloud.</td>
<td>Visibility helps in taking avoidance and escape measures.</td>
</tr>
<tr>
<td>The LFL (Lower Flammable Limit) concentration is always within the visible cloud for relative humidity above 55%.</td>
<td>Photographs of LNG visible plumes are useful approximations of the flammable cloud.</td>
</tr>
<tr>
<td>LNG vapours will quite quickly warm to ambient temperatures by conduction and/or by dilution with air.</td>
<td>By air mixing alone, the specific gravity of an evaporated LNG vapour plume approaches unity asymptotically from above by temperature warming and from below by increasing molecular weight.</td>
</tr>
<tr>
<td>LNG vapours will ultimately warm enough to become buoyant and lift off, reducing the chance of ignition.</td>
<td>Temperature and molecular weight have opposite effects on the vapour - specific gravity. The molecular weight effect always drives an ultimate specific gravity less than 1.0. As warming occurs by dilution and conduction, then a vapour plume from an LNG spill is likely to rise (lift off) at some point downwind of the spill.</td>
</tr>
<tr>
<td>LNG has slightly higher energy density than gasoline (10 – 11% higher).</td>
<td>LNG develops relatively high flame temperatures for small fires that are not oxygen starved.</td>
</tr>
<tr>
<td>LNG has a strong advantage over burning liquid hydrocarbons or coal in generating less CO₂ per unit of energy (81 - 83% as much).</td>
<td>LNG is preferred over liquid hydrocarbons or coal for environmental impact.</td>
</tr>
<tr>
<td>LNG liquid does not burn or explode.</td>
<td>As for all hydrocarbon liquids, only the vapour above the liquid burns and can explode if sufficiently confined or congested.</td>
</tr>
<tr>
<td>The vapour above LNG must mix with air to below 15% and above 5% of natural gas concentration to be flammable.</td>
<td>Much of the vapour cloud above an LNG spill is not in the flammable range. Only a fraction of the plume will ignite.</td>
</tr>
<tr>
<td>Methane and light composition natural gas have a relatively high lower</td>
<td>An LNG vapour plume contour to the LFL does not cover</td>
</tr>
</tbody>
</table>
**Flammability limit (LFL, 5% compared to 1% for gasoline or 0.7% for crude oil).**  

The burn rate of an LNG pool fire on land is "above the curve" for other paraffin hydrocarbons.

LNG pool fires produce relatively little smoke.

Applying dry chemical powder is the only way to extinguish an LNG fire. The fire will continue until all the fuel is burned.

LNG spills at a regasification terminal are directed to a sump, so ignition results in a pool fire at a safe location.

Unconfined or partially confined LNG vapour/air mixtures do not detonate (form a sonic velocity explosion that self-propagates as discussed later).

LNG vapour has low reactivity for explosion propagation.

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<table>
<thead>
<tr>
<th>as large an area as an otherwise equivalent gasoline spill.</th>
<th>The higher burn rate contributes to a tall fire of shorter duration, than a corresponding amount of higher - chain hydrocarbon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright nonsmoky flames generate higher emitted radiation, and thus LNG fires radiate more heat than heavier hydrocarbons. Larger pool fires produce more smoke, so the emissive power drops off with pool size, and this is believed true for the largest LNG pool fires as well.</td>
<td>Water will not extinguish an LNG fire. Preinstalled firefighting foams may slow the fire. However, extinguishment does not stop liquid boil off and hence vapour cloud formation; thus, controlled burning can be safer than extinguishment. Complete burning avoids late ignition flash fire.</td>
</tr>
<tr>
<td>The terminal design can provide adequate insulation of nearby structures. Water spray systems are being evaluated to reduce radiant energy at important locations from a sump pool fire.</td>
<td>Considerable congestion and/or a high – energy ignition source is required to explode as a deflagration (a subsonic explosion that decays upon burning outside of a high – congestion zone).</td>
</tr>
<tr>
<td>The flame speed of a natural gas deflagration is lower than other hydrocarbons because of its low reactivity.</td>
<td></td>
</tr>
</tbody>
</table>
3 LNG supply and fuelling infrastructure

An LNG fuelling station has several features that make it physically unique from the diesel and gasoline fuelling stations. The primary difference is due to the cryogenic properties of LNG fuel, which require specialized equipment to store, pump, and dispense a fuel with an approximate temperature of -161.5°C (-260°F).

The basic components of an LNG fuelling station are presented in the following figure.

![Figure 3-1 Basic components of an LNG fuelling station](image)
4 Analysis and security measures

The security measures most appropriate to adopt by this kind of installation lead to the elaboration of specific risk analysis. From the various methods to do this, the most notable methodology is the HAZOP (Hazard and Operability). This method consists of a systematic and rigorous technique for risk identification, which can be obtained recommendations for equipment design improvement and health and safety measures.

According to regulations NFPA 59A “Standard for the Production, Storage and Handling of the Liquefied Natural Gas” and EN 1473 “Installation and equipment for liquefied natural gas – Design of onshore installations” LNG installations must have an emergency cut system which carry to LNG station to a secure position in an emergency situation.

For this reason, the regulations ANSI/ISA – S84.01 – 1996 “Application of Safety Instrument Systems for the process industries” and IEC 61508 “Functional Safety of electrical/electronic/programmable electronic safety related systems” provides that it is necessary to perform a assignation of the SIL index for all interlocks or emergency systems existing in the different installation equipment. The SIL evaluation consists of an extension of the hazard process analysis (Process Hazard Analysis PHA) for which the HAZOP methodology is presented in the same manner as it is explained before.

The first application of this methodology is to risk identification of the design first steps; the step of the design is the best moment to introduce change and modification.

It also it is necessary to know that the European regulation EN 1473 “Installation and equipment for liquefied natural gas – Design of onshore installations” provides that all projects about LNG must be subject to an accurate revision of the possible risk situations and, in particular, the regulation provides that after the engineering diagrams and instrumentation (P&M) are, sufficiently developed and approved, it is necessary to do a HAZOP study of the installations.

This study includes the investigation about possible deviations in front of the design conditions for a lines and elements of a determinate unity of process.

The working group with a brainstorming process identify deviation of the normal conditions of the process in some key points during the process.

Finally, the identification of the unintended consequences gives as result recommendations for improving the process.

Parallel to the preparation of the HAZOP analysis, need to be allocated a SIL index to all security instrumentation systems or emergency interlock in the installation.

Following it is explained an integrated assessment process for safety assurance of development proposals, which are potentially hazardous. The integrated hazards-related assessment process comprises:

1. A preliminary hazard analysis undertaken to support the development application by demonstrating that risk levels do not preclude approval...
2. A hazard and operability study, fire safety study, emergency plan and an updated hazard analysis undertaken during the design phase of the project...
3. A construction safety study carried out to ensure facility safety during construction and commissioning, particularly when there is interaction with existing operations.
4. Implementation of a Safety Management System to give safety assurance during ongoing operation.
5. Regular independent hazard audits to verify the integrity of the safety systems and that the facility is being operated in accordance with its hazards-related conditions of consent.

The process is shown below:

![Figure 4-1 The Hazard – Related assessment process](image)

An important element of any system for the prevention of major accidents is conducting a hazard and operability study (HAZOP) at the detail design stage, of the plant in general and the operating and safety control systems in particular. HAZOPs seek to minimize the effect of an atypical situation in the operation/process by ensuring that control and other safety systems such as functional safety (e.g. emergency safe shutdown) are in place and work with a high level of reliability to achieve a safe outcome from a situation that could have resulted in a major accident.

The HAZOP process is used to identify potential hazards and operational problems in terms of plant design and human error. The technique is applied during final design of the process and plant items before commencement of construction.

HAZOPs have also proven to provide financial benefits to the plant owner/operator by minimizing the time and money spent in installing add on control and safety systems, the need for which may become
evident at the time of plant commissioning in the absence of a HAZOP. On the operability front benefits are gained by implementing at design stage, the remedial recommendations to operability issues identified during the HAZOP.

This advisory paper aims to provide guidance to all persons associated with the design and operation of a facility to appreciate the need for a HAZOP and also the general procedure that is followed in carrying out a HAZOP and reporting the study results. It gives a broad indication of what is required in undertaking a HAZOP with a list of references for further study.

4.1 Hazard and Operability study methodology

Essentially, the HAZOP examination procedure systematically questions every part of a process or operation to discover qualitatively how deviations from normal operation can occur and whether further protective measures, altered operating procedures or design changes are required.

The examination procedure uses a full description of the process which will, almost invariably, include a P&ID or equivalent, and systematically questions every part of it to discover how deviations from the intention of the design can occur and determine whether these deviations can give rise to hazards.

The questioning is sequentially focussed around a number of guide words which are derived from method study techniques. The guide words ensure that the questions posed to test the integrity of each part of the design will explore every conceivable way in which operation could deviate from the design intention.

Some of the causes may be so unlikely that the derived consequences will be rejected as not being meaningful. Some of the consequences may be trivial and need be considered no further. However, there may be some deviations with causes that are conceivable and consequences that are potentially serious. The potential problems are then noted for remedial action. The immediate solution to a problem may not be obvious and could need further consideration either by a team member or perhaps a specialist. All decisions taken must be recorded. Appendix 2 provides a recording example. Secretarial software may be used to assist in recording the HAZOP, but it should not be considered as a replacement for an experienced chairperson and secretary.

The main advantage of this technique is its systematic thoroughness in failure case identification. The method may be used at the design stage, when plant alterations or extensions are to be made, or applied to an existing facility.

4.2 Sequence of examination

Figure 4-2 illustrates the logical sequence of steps in conducting a HAZOP. The main elements under consideration are:

- intention
- deviation
- causes
- consequences
  - hazards
Typically, a member of the team would outline the purpose of a chosen line in the process and how it is expected to operate. The various guide words such as more are selected in turn. Consideration will then be given to what could cause the deviation.

Following this, the results of a deviation, such as the creation of a hazardous situation or operational difficulty, are considered. When the considered events are credible and the effects significant, existing safeguards should be evaluated and a decision then taken as to what additional measures could be required to eliminate the identified cause. A more detailed reliability analysis such as risk or consequence quantification may be required to determine whether the frequency or outcome of an event is high enough to justify major design changes.

4.3 Details of study procedure

The study of each section of plant generally follows the following pattern:

- The process designer very briefly outlines the broad purpose of the section of design under study and displays the P&ID (or equivalent) where it can be readily seen by all team members.
- Any general questions about the scope and intent of the design are discussed.
- The first pipeline or relevant part for study is selected, usually one in which a major material flow enters that section of the plant. The pipeline is highlighted on the P&ID with dotted lines using a transparent pale coloured felt pen.
- The process designer explains in detail its purpose, design features, operating conditions, fittings, instrumentation and protective systems, etc., and details of the vessels immediately upstream or downstream of it.
- Any general questions about the pipeline or relevant part are then discussed.
- The detailed 'line by line' study commences at this point. The discussion leader takes the group through the guide words chosen as relevant. Each guide word or prompt, such as HIGH FLOW, identifies a deviation from normal operating conditions. This is used to prompt discussion of the possible causes and effects of flow at an undesirably high rate. If, in the opinion of the study team, the combination of the consequences and the likelihood of occurrence are sufficient to warrant action, then the combination is regarded as a 'problem' and minuted as such. If the existing safeguards are deemed to be sufficient then no further action is required. For major risk areas the need for action may be assessed quantitatively using such techniques as Hazard Analysis (HAZAN) or Reliability Analysis. For less critical risks the assessment is usually based on experience and judgement. The person responsible for defining the corrective action is also nominated.
- It should always be remembered that the main aim of the meeting is to find problems needing solution, rather than the actual solution. The group should not be tied down by trying to resolve a problem, it is better to proceed with the study, deferring consideration of the unsolved problems to a later date.
- When the guide word requires no more consideration, the chairperson refers the team to the next guide word.
- Discussion of each guide word is confined to the section or pipeline marked, the vessels at each end and any equipment, such as pumps or heat exchangers, in between. Any changes
agreed at the meeting are minuted, and where appropriate, marked on the P&ID or layout with red pen.

- When all guide words have been covered, the line is fully highlighted to show that it has been completed, and the next line is chosen.
- When all the lines in a plant sub-section have been reviewed, additional guide words are used for review (overview) of the P&ID as a whole.

4.4 HAZOP effectiveness

The effectiveness of a HAZOP will depend on:

- The accuracy of information (including P&IDs) available to the team — information should be complete and up-to-date
- The skills and insights of the team members
- How well the team is able to use the systematic method as an aid to identifying deviations
- The maintaining of a sense of proportion in assessing the seriousness of a hazard and the expenditure of resources in reducing its likelihood
- The competence of the chairperson in ensuring the study team rigorously follows sound procedures.

Key elements of a HAZOP are:

- HAZOP team
- Full description of process
- Relevant guide words
- Conditions conducive to brainstorming
- Recording of meeting
- Follow up plan

The HAZOP team

The group carrying out the HAZOP will typically consist of a team of approximately five to eight people. Team members should possess a range of relevant skills to ensure all aspects of the plant and its operations are covered, Engineering disciplines, management, and plant operating staff should be represented. This will help prevent possible events from being overlooked through lack of expertise and awareness.

It is essential that the chairperson is experienced in HAZOP techniques. This will ensure that the team follows the procedure without diverging or taking short-cuts. Where the HAZOP is required as a condition of development consent, the name of the chairperson is typically required to be submitted to the Director General of Planning or the Director General’s nominee for approval prior to commencement of the HAZOP.

Apart from the chairperson, it is important that the study team be highly familiar with the information contained in the P&ID of the plant or alternative description of the process being considered. For existing plant, the group should include experienced operational and maintenance staff.
Figure 4-2 HAZOP procedure illustration
4.5 Non-traditional HAZOP equivalents

4.5.1 Computer HAZOP (CHAZOP)

The use of electrical, electronic or programmable electronic (E/E/PE) systems in safety related applications is steadily growing. This applies to computer based instrumentation, control and safety related functional applications in modern chemical plants and related industrial situations. Difficulties arising due to the malfunction of such systems are also increasing, particularly as experience with such systems flags new types of problems which were not encountered in older plant designs. The interface with modern electronic control/protective systems remains a potential weakness in the overall reliability of these systems.

The E/E/PE systems relating to the operations function of the plant may be considered as being regularly tested “on the run”. However, the same may not be true for the safety related systems which are called upon to perform as intended infrequently in the event of a failure or dangerous situation.

Dangerous situations can arise due to:

- the requirements of the functional safety system (hardware/software) being inadequately specified at design stage
- modifications to software/hardware not being adequately considered
- common cause failures
- human error
- random hardware faults
- extreme variations in surrounding conditions, e.g. electromagnetic, temperature, vibration
- extreme variations in supply systems e.g. low or high supply voltage, loss of air pressure for emergency shutdown, voltage spikes on resumption after a power outage

The hazard analysis determines whether functional safety is necessary to ensure adequate protection. Functional safety is part of the overall safety that depends on a system or equipment operating correctly in response to its inputs. For example, an overpressure protection system using a pressure sensor to initiate the opening of a relief device before dangerous high pressures are reached is an instance of functional safety.

Two types of requirements are necessary to achieve functional safety:

- Safety function requirements (what the function does); and
- Safety integrity requirements (the likelihood of a safety function being performed satisfactorily).

The safety function requirements are derived from the hazard analysis and the safety integrity requirements are derived from the risk assessment. The HAZOP or CHAZOP should review the safety related systems that must operate satisfactorily to achieve a safe outcome in the event of an incident/situation with potential to result in a dangerous failure.

The aim should be to ensure that the safety integrity of the safety function is sufficient to ensure that no one is exposed to an unacceptable risk associated with the hazardous event.
4.5.2 FMEA

Failure Modes and Effects Analysis (FMEA) uses a similar ‘what if?’ approach to a HAZOP but has as its objective the identification of the effects of all the failure modes of each piece of equipment or its instrumentation. As a result, FMEA identifies single failure modes that can play a significant part in an accident. It is not effective, however, at identifying combinations of equipment failures that lead to accidents. Human operators are not usually considered specifically in FMEA, even though the effects of operational errors are usually included in the equipment failure mode.

FMEA is similar in methodology to a HAZOP but with a different approach. Whereas the HAZOP evaluates the impact of a deviation in the operating conditions to a level outside the design range such as MORE FLOW or LOW TEMPERATURE FMEA uses a systematic approach to evaluate the impact of a single equipment failure or human error, in turn, in the system or plant.

In FMEA, the reason or cause for the equipment failure is not specifically considered. This is different to a HAZOP in which the cause/s for the deviation have to be assumed or agreed by judgement and experience, since it is the cause that the HAZOP initially addresses. The FMEA methodology assumes that if a failure can occur, it must be investigated and the consequences evaluated to verify if the failure can be tolerated on safety grounds or if the remaining serviceable equipment is capable of controlling the process safely.

As for HAZOP, to be effective, the FMEA needs a strong, well led team with wide cumulative experience. The initial briefing by the leader and the contributions expected from each member are similar to that in a HAZOP.

The results of the analysis are recorded as in a HAZOP. A typical record sheet is included at Appendix 3. The recording should be in the same format for the whole plant in order to facilitate reviews of the analysis and maintenance of records.

In carrying out the FMEA, the process flow diagrams and the P&IDs are first studied to obtain a clear understanding of the plant operation. Where a part of a process is being analyzed, it may be necessary, in addition, to include the failure modes of equipment immediately outside the analysis area and the consequence of the failure on the plant/process section being analyzed.

4.5.3 Other

An expanded approach put forward by Pitblado (et al) [1989]) is to conduct a multitiered HAZOP Study in which the conventional HAZOP forms only the first tier. A computer system HAZOP (CHAZOP) becomes the next stage, A ‘Human Factors’ HAZOP is the third and final stage. Different guide words are utilized at each tier.

There is every reason to believe that, with appropriately modified guide words, the HAZOP technique can be applied to situations which are not strictly process ones. Even if a strictly disciplined technique were not employed, a searching study of materials handling and warehousing and even of mining operations would benefit from the group study approach.
5 General safety, operation and maintenance of LNG stations

Below a brief summary is shown of the major hazards which are explained in the following subsections related with the health effects, source of LNG hazards, accidental release LNG and the major LNG hazards.4

Like any fuel, safe handling procedures and proper safety precautions must be followed when working with LNG. Many years of experience using natural gas vehicles have proven that natural gas can be used safely as a fuel for vehicles. However, using LNG, or any other alternative fuel, involves different safety procedures than most fuel providers and consumers are accustomed to following.

The main health effects shown below:

- **Asphyxiant**: The principal component of natural gas is methane, and is not considered to be toxic; this is a gas simple asphyxiant, which is a health risk simply because it can displace oxygen in a closed environment.
- **Skin**: Workers can receive cryogenic burns from direct body contact with cryogenic liquids, metals, and cold gases. Exposure to LNG or direct contact with metal at cryogenic temperatures can damage skin tissue more rapidly than when exposed to vapour. It is also possible for personnel to move away from the cold gas before injury.
- **Inhalation**: Liquefied Natural Gas vapours are considered to be non-toxic by inhalation. Inhalation of high concentrations may cause central nervous system depression such as: dizziness, drowsiness, headache, and similar narcotic symptoms, but no long-term effects. Numbness and vomiting have been reported from accidental exposure to high concentrations.

The source of LNG hazards occurs by:

- Liquid leaks under pressure (pump and pipe leaks)
- Liquid leaks from storage tanks (the head pressure is usually atmospheric)
- Rollover of an LNG storage tank
- Liquid pools evaporating to form a flammable vapour plume
- Liquid leaks injected into water under pressure or from a moderately high elevation giving rise to a rapid phase transition (RPT) explosion.

An accidental release of LNG can pose the following hazards:

- Radiation burns and structural weakening from flash fire, pool fire, or jet fire
- Overpressure and impulse from partially confined vapour cloud explosion
- Rapid spreading, evaporation and possibly overpressures from a RPT explosion
- Asphyxiation

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Freeze burns
Rollover

5.1 Fire

A leak from of LNG an insulated container to the ground can pose a potential flash fire and a subsequent pool fire, similar to that gasoline or diesel. The reason to this consequence is that the LNG flows downhill and then begins to vaporize. As the gas warms up, it mixes with the surrounding air and begins to disperse, with the consistent formation of a cloud. This cloud will ignite if it encounters an ignition source, while it has the concentration within its flammability range by volume (5-15%). The fire's thermal radiation could harm people and damage surrounding equipment and property.

There is a low risk of a jet fire or “torch fire” because the LNG tank has low pressure; this means that the liquid or vapour will not discharge from a tank puncture in a high velocity jet (which is possible in a CNG tank).

Other possibility related with the fire hazard is when the leak occurs in a confined space where the vapours builds up to a 5-15% concentration, there is the risk of an explosion upon contact with a high-temperature heat source. This combustion would be similar to a gas explosion from a traditional indoor gas leak.

5.1.1 Flash fire:

A. Hazard description

A flash fire occurs when a cloud of gas burns without generating any significant overpressure. The cloud of methane (and the mix of ethane and propane) can only be ignited where the concentration is above the Lower Flammable Limit (LFL see figure before). The flammable range for methane, as we explained before, is 5% to 15% in mixture with air. Below 5% mix (methane/air) it will be too lean to ignite, and above 15% it will too rich to ignite.

The gas clouds can only be ignited at the edge as they disperse and meet an ignition source. An ignited cloud will “flash back” across all its flammable mass. It will then burn at the UFL boundary until the entire hydrocarbon is consumed. The duration of the flash fire is relatively short, it may stabilize as a continuing jet fire or pool from the leak origin.

B. How to avoid it

The following safety instructions are to be undertaken in order to avoid fire:

- All sources of ignition in the safety zone are to be strictly prohibited
- Organise and train all personnel for fire fighting
- Advise where smoking and naked fires are NOT allowed
- Fire and gas leakage safety barriers are to be established
- Full firefighting procedures and instructions are to be established
- Pool fire
- Forbidden using mobile phones

For large spills, air cannot transfer enough heat to vaporize much LNG so a part of the spill is likely to end up in a liquid poll. A pool fire may result after a flash fire. A LNG pool fire generates significant thermal radiation with the surface emission power around 200 kW/m² (a person in protective clothing...
will shrink withstand 12 kW/m² for a short time). Once combustion is added to evaporation, the pool will shrink significantly in size to a sustainable pool fire diameter.\(^5\)

5.1.2 Jet fire

A. Hazard description

Jet fires are burning jets of gas or atomized liquid whose shape is dominated by the momentum of release. Jet fires typically result from gas or condensate releases from high-pressure equipment. Jet fires may also result from releases of high-pressure liquid containing dissolved gas, due to the gas flashing off and turning the liquid into a spray of small droplets. Typical conditions for this are at a pressure over 2 bar.

B. How to avoid it

The unignited gas release may be mitigated by use of water sprays. The jet fire obviously requires cooling of heat affected exposures and plant involved, while reducing and then isolating the gas feed pressure.

Dry chemical may be used for extinguishment, if safe to do so – if the release is of a manageable size for responders – but this needs to consider residual gas developing into a flammable gas cloud, thereby creating a larger and potentially more dangerous incident.

C. Tactics to mitigate

- Isolate pressure source (pumps/operations);
- Prioritise cooling;
- Cool any flame affected steelwork or plant;
- Cool radiant heat affected steelwork/plant;
- Foam cannot extinguish a pressure fire (if C5 or C6 liquids are involved);
- Dry chemical may extinguish jet fire – but pressure gas cloud will remain.
- Refrigeration

5.2 Pool and brittle failure

To create any brittle fracture of structural steels it is necessary that the material soak in cryogenic fluid for a period of time, and create a standing pool of LNG is not easy. The liquid is always under some level of pressure, when it is ejected from a breach in a container a large portion of it vaporizes before it can settle into a puddle of standing liquid. The thermodynamic certainly is that, to ambient pressures, initially, the reduction in pressure forces some of the internal heat of the liquid to flash boil itself.

The vaporization occurs between 5 and 25% of the liquid, depending on its initial pressure. The remaining liquid stream breaks up and atomizes in the air. This break up accelerates the heat transfer from the air and evaporates another 15-20% of the stream, depending on the velocity. The rest of the product falls to the ground. Before it can settle into a puddle, it must cool the surrounding ground to cryogenic temperatures. Depending on the thermal mass of the surroundings, another additional 20-25% of the rest of the liquid can quickly evaporate.

\(^5\) SOURCE: LIQUIFIED NATURAL GAS (LNG) EMERGENCY RESPONSE PLAN – Clean energy
Usually the mechanisms of flash and atomization result in that none liquid can survive to the ground. In rare cases can begin a puddle, but the net volume of any such puddle is a small fraction of the initial volume. This all means that the practical extended exposure to cryogenic temperature is limited. The direct liquid spray is a local concern and can create local cracking.

In contrast, a diesel or gasoline spill has some additional risk due to the persistence of the spill. However, LNG evaporates and disperses quickly. Gasoline spills will not have such vaporization but will create large pools. And diesel spills often result in expensive clean-up measures to protect surface water and groundwater.

If the pool is larger, the dangerous situation is major.

5.2.1 Brittle fracture and cryogenic burns

A. Hazard description
In order to get natural gas in liquid phase it needs to be cooled down below its boiling temperature of -161.48 ºC (it must be cryogenic). The LNG cryogenic properties are particular and, it thus requires especial attention. This phase of the fuel may represent thermal hazards to personnel and also, the low temperatures may mean a problem of the materials relation with this liquid cryogenic. While stainless steel and aluminium will remain ductile, carbon steel and low alloy steel will become brittle and fractures are likely if exposed to such low temperatures.

B. How to avoid it
With this knowledge, it is clear that the materials of the elements which be going to be in contact with the LNG cryogenic must be selected with carefully. This is important to ensure the durability of the elements and to avoid possible problems unwanted.

Containment systems surrounding an LNG storage tank, thus, are designed to contain up to 110 percent of the tank’s contents. Containment systems also separate the tank from other equipment. Moreover, all facility personnel must wear gloves, face masks and other protective clothing as a protection from the freezing liquid when entering potentially hazardous areas. This potential hazard is restricted within the facility boundaries and does not affect neighbouring communities.

5.3 Phase change and overpressure considerations
An important characteristic of the LNG is that offers greater fuel density than CNG. In the following subsections it is explained the study about all possibilities of fails in relation with phase change and over pressure. e. g. if the LNG container is heated so the outer tank fails, and the insulation fails and the tank’s pressure relief devices fails, then the inner tank would not be structurally able to hold the gas contents at the resulting ambient or high temperature and the tank would fail.

5.3.1 Container overpressure failure
This failure represents an extremely low risk, and then it is explained the reasons for this low risk.

The transition of LNG to a gaseous state can, in certain situations, lead to an explosive event. These explosions are related with the rapid phase transformation. It should be noted that as LNG is stored at low pressure, the immediate explosion due to rapid pressure release from tank puncture is not a credible danger. But it is true that LNG storage tank could fail due to overpressure (e. g. due to
ambient heat gain boil off or due to external fire exposure). The size and number of pressure release devices and the safety factor in the strength of LNG tanks drives the probability of vessel failure due to overpressure to an extremely low risk.

5.3.2 Rapid phase transition (RPT)

If LNG comes into contact with water, it will float until it vaporizes. If large volumes of LNG are released on water, direct water LNG contact can lead to a burst of heat transfer and rapid LNG vaporization. The rapid phase transition (RPT) range from small pops to moderate explosions, large enough to potentially damage lightweight structures. Given the relatively small volumes of LNG involved and low potential LNG release rates spilled LNG coming into contact with a body of water such as a river or lake, the potential power of an RPT in LNG transportation is very small. Studies have shown that in order to have meaningful energy release from an RPT the leak rate must exceed 10,000 gallons per minute which is not credible scenario for the equipment being assessed in this report.

5.3.3 Boling liquid expanding vapour explosion (BLEVE)

Often a BLEVE is associated with external fire exposure where the fire weakens the container holding a flammable liquid and heats the contents of the tank. One critical mitigating factor is the US requirement for containers to be insulated with materials that do not detach during fire. The design specifications of LNG tank insulation built to US standards require insulation jackets that remain in place during a fire. The low temperature nature of the LNG and the thermal isolation provided by the jacket are designed to keep the upper portion of an LNG tank from reaching critical temperature.

The behaviour of containers without appropriately designed insulation can make them more susceptible to BLEVE events:

The pressurized liquid in an un-insulated container will boil, increasing its vapour pressure. The un-insulated nature of the vessel and the lack of the thermal mass of liquid on the top of the tank allows the upper portion of the vessel wall to increase in temperature which reduces its strength. If the temperature of the material gets above a critical level, the container fails causing the vessel's high-pressure vapour to be released. The rapid phase change can create an explosive pressure surge which shatters the container. That localized failure causes the rapid pressure reduction and subsequent phase change and pressure surge. The leaking fuel then helps feed the fire. As discussed elsewhere, the pressure relief devices (PRDs) should be sized to keep the pressures inside the tank from exceeding the allowable limits specified by the vessel code, reducing the chance of such events.

There was an incident in Spain where foam insulated single-walled LNG trailer exploded during a fire. In this incident the insulation did not remain in place during the accident and fire, likely contributing to the severity of the incident. U.S. codes and design standards concerning insulating material and application of double-walled trailers for transporting LNG are intended to mitigate against these failure modes.

A. Hazard description
   o A BLEVE involving an LNG storage tank is highly unlikely.
   o BLEVE’s have occurred with Liquefied Petroleum Gas tanks but not LNG tanks.

B. How to avoid it
   o LNG tanks are double-walled, well insulated and vacuum jacketed.
   o The outer shell will prevent direct flame impingement on the inner tank.
Mechanical insulation between outer & inner wall drastically slows heat transfer to LNG.

C. Tactics to mitigate

• Precautionary non-essential personnel evacuation to minimum distance of 1,000 metres;
• Cool tanker if on fire but expect greater fire intensity if liquid LNG involved in fire;
• Cool any nearby tanker loading/unloading plant, equipment or other heat affected exposures;
• Evacuation of all responders once cooling in place.

5.3.4 Vapour cloud explosion (VCE)

If a flammable vapour cloud accumulated in a highly congested area (or a confined area) and the cloud is ignited the combustion process can be so rapid that an explosion pressure wave is created. Such explosions typically require large vapour clouds and substantial congestion to create blast pressures that would injure people or damage property. Large ignited vapour clouds that are in the open, for example on a street, will not generate blast pressures, but the same cloud in a more contained area, say a heavily wooded area with a lot of undergrowth, cloud do so. A VCE also requires a fast flame speed or flame reactivity. Methane class as one of the least flame reactive hydrocarbons and does not detonate in open air.

A. Hazard description

As LNG leaves a temperature-controlled container, it begins to warm up, returning the liquid to a gas. Initially, the gas is colder and heavier than the surrounding air. It creates a fog – a vapour cloud – above the released liquid. As the gas warms up, it mixes with the surrounding air and begins to disperse. The vapour cloud will only ignite if it encounters an ignition source while concentrated within its flammability range. Vapour cloud characteristics

• Vapour with downwind plume will produce a long, thin cigar shaped vapour cloud.
• Visibility is due to condensed water vapours.
• The danger may not always be within the visible cloud.
• Can travel considerable distances before concentrations fall below (LFL).
• The danger distance decreases as wind speed increases because it dilutes the gas.
• Containment walls will delay vapours from traveling downwind.
• Nearly all of the vapour clouds come from air mixing with the vapour.

B. How to avoid it

Safety devices and operational procedures are intended to minimize the probability of a release and subsequent vapour cloud having an affect outside the facility boundary.

5.3.5 Vapour cloud ignition

A. Hazard description

The ignition of an unconfined LNG vapour cloud by typical ignition sources does not produce a pressure wave.

• Ignition of LNG vapours in a confined space can produce overpressures strong enough to cause severe damage
• Ignition of a diluted cloud may produce limited thermal radiation
B. **How to avoid it**

- Vacuum-relief valves will be provided.
- Pressure relief system.
- Pressure and level sensors provided to the tank.
- Appropriate spacing and layout to protect adjacent tank from radiating heat and fire.
- Gas detectors provided in the tanks area.

### 5.3.6 Trapped LNG

#### A. Hazard description

If LNG is trapped in the piping or somewhere along the transfer line, a phase transition will cause a local pressure build-up. The expansion can potentially cause a pipe burst leading to a significant release of natural gas or LNG depending on the size of the burst and operating conditions.

#### B. How to avoid it

All pipe sections and tanks shall therefore be secured with thermal relief valves. Always take necessary precautions when encompassing system modification or maintenance.

### 5.4 Cryogenic burns/frostbite

LNG and cold vapour clouds can cause cryogenic burns or frostbite to unprotected skin in the event of a large leak. In addition, insufficient insulation could cause metal equipment to reach very low temperatures and indirect contact with these parts could harm bare skin. Proper design and maintenance ensure sufficient insulation of pipes and equipment to avoid injuries caused by contact with cold surfaces. Ice or frost may form on cold equipment to warn of such a hazard. This is comparable to the risk of high-temperature burns through contact with the exhaust of a traditional engine if its insulation failed. Macro Technologies currently supplies LNG Quick Connect Nozzles for refuelling vehicles. The equipment should permit fuelling connections without leaking of LNG. The handles on the nozzle should not cause cryogenic burns. Even so, the company urges that the operators be familiar with the station safety procedures and that the fueller wears: full face shield; thermal gloves approved for cryogenic use; a cryogenic smock (to keep splashed liquid off clothes) and solid shoes capable of withstanding cryogenic spills. Maintenance of LNG fuel systems in particular requires training specific to cryogenic systems since there is a higher probability of contacting cold liquid or gas during maintenance activities than in normal operation.

### 5.5 Environmental effects

LNG spills completely evaporate leaving no residue that could harm ground water or waterways. LNG spills and natural gas venting would result in a release of methane to the atmosphere resulting in greenhouse gases that needs to be minimized during normal operation.

#### 5.5.1 Asphyxia

#### A. Hazard description

Methane, or natural gas, is not toxic. However, in the case of a release of natural gas in an enclosed or semi-enclosed area it can result in asphyxiation due to the lack of oxygen caused by decrease of the partial pressure of oxygen in the inhaled air, which is established when mixing methane and air. Concentrations of 50% by volume (methane in air) will cause obvious suffocation symptoms like
difficulties in breathing and rapid breathing at the same time as the ability to response deteriorates and muscle coordination weakens.

5.6 Earthquakes and terrorism

A. Hazard description

LNG terminal facilities might be physically attacked with explosives or through other means. Some LNG facilities may also be indirectly disrupted by “cyberattacks” or attacks on regional electricity grids and communications networks which could in turn affect dependent LNG control and safety systems.

The September 11, 2001 terrorist attacks in the United States focussed more attention on the vulnerability of LNG infrastructure. A number of technical studies have been commissioned since the attacks which has caused some controversy due to differing conclusions about the potential public hazard of LNG terminal accidents or terror attacks. (Parfomak (2005) CRS Report RL3220). One widely cited report from Sandia National Laboratories (and sponsored by the U.S. Department of Energy) noted that more studies are needed for analyzing tanker-scale spills on waters.⁶

5.7 Safety considerations for LNG fuelling stations

Still, the LNG fuelling process does contain some potential hazards, such as the potential for leaking gas to collect in flammable concentrations or if personnel are exposed to the cryogenic temperatures of the fuel.

The LNG industry has taken many steps over the years to develop technology and implement protocols for the safe use, transport, and dispensing of this fuel. An example of the typical safety measures in place at an LNG fuelling station is presented in Figure 5-1.

⁶ SOURCE: Liquefied Natural Gas (LNG) Import Terminals: Siting, Safety and Regulation - Paul W. Parfomak & Aaron M. Flynn – CRS Report for Congress
In relation with the properties, hazards and infrastructure of LNG station how it has explained before, below there is a description of the major hazards relating with the LNG stations.

This explanation is distributed in the following subsections, first the general properties affecting fire hazards, second fire hazards during transport, third fire hazards during storage tanks, after fire hazard during storage and the last other hazards.

5.7.1 General properties affecting fire hazards

Even though the end product of the use of CNG and LNG for vehicular applications is essentially the same, the general properties affecting safety are quite different. On one hand, LNG is a more refined and consistent product with none of the problems associated with corrosive effects on tank storage associated with water vapour and other contaminants. On the other, the cryogenic temperature makes it extremely difficult or impossible to add an odorant. Therefore, with no natural odour of its own, there is no way for personnel to detect leaks unless the leak is sufficiently large to create a visible condensation cloud or localized frost formation. It is essential that methane gas detectors be placed in any area where LNG is being transferred or stored.

The cryogenic temperature associated with LNG systems creates a number of generalised safety considerations for bulk transfer and storage. Most importantly, LNG is a fuel that requires intensive
monitoring and control because of the constant warming of the fuel, which takes place due to the extreme temperature differential between ambient and LNG fuel temperatures. Even with highly insulated tanks, there will always be a continuous build-up of internal pressure and a need to eventually use the fuel vapour or safely vent it to the atmosphere.

The constant vaporization of the fuel also has an interesting effect on the properties of the fuel. The methane in the fuel will boil off before some of the heavier hydrocarbon components such as ethane, propane, and butane. Therefore, if LNG is stored over an extensive period of time without withdrawal and replenishment the methane content will continuously decrease and the actual physical characteristics of the fuel will change to some extent. This is known as “weathering” of the fuel, for further information check Deliverable 3.2.Gas Quality.

5.7.2 Fire hazards during transport

The first concern with implementing an LNG fuel station program is the bulk transportation of the LNG fuel over the roadways from the liquefaction plant to the fuelling station. LNG tanker trucks, typically containing 37,000 to 45,500 litres of fuel (allowable max. total gross weight loaded is 40,000 kg with the exception of Scandinavian states, maximum transportable volume of LNG is therefore cca 41,000 litres), would be utilized for the refuelling process, which is similar to that for other fuels but with several additional safety mechanisms. The double-walled construction of the LNG tanker truck is inherently more robust than the equivalent tanker truck designed for the transport of other liquid fuels. Therefore, the transport of LNG is considered safer from the perspective of fuel spills resulting from a tank rupture during an accident. A rupture of the outer tank wall would cause the loss of insulation and result in the venting of LNG vapour. While this is of concern, it is relatively minor as compared to the prospect of an LNG spill.

In the event that the LNG tanker truck is ruptured in a transport accident and the LNG is spilled, there is a possibility of a fire because a flammable natural gas vapour/air mixture could be formed in the vicinity of the LNG pool. In an accident situation, there is a high likelihood of ignition sources due to electrical sparking, hot surface, or possibly a fuel fire created from the tanker truck’s engine fuel or other vehicles involved in the accident. The vapour cloud from an LNG pool will be denser than the ambient air; therefore, it will tend to flow along the ground surface, dispersed by any prevailing winds.

When spilled along the ground or any other warm surface, LNG boils quickly and vaporizes. A high volume spill could cause a pool of LNG to accumulate and the boiling rate will decrease from an initial high value to a low value as the ground under the pool cools. The heat release rate from an LNG pool fire will be approximately 60% greater than that of a gasoline pool fire of equivalent size.

5.7.3 Fire hazards due to storage tanks

The transfer of LNG from a tanker truck to storage tanks is a complex process that involves the active participation of both the tanker truck driver and a representative of the station operator. A partial listing of some of the steps involved provides some indication of the safety precautions that are necessary.

After the truck wheels are chocked and the engine is shut off, a grounding cable is attached to the truck to ground any electrostatic discharge.
A flexible liquid transfer hose is attached to the tanker and purged of air. A station operator representative will open the storage vessel liquid fill line and the driver will open the trailer’s main liquid valve.

The safety features that are typical of truck storage transfer of LNG include equipment design such as trailer liquid valves that are interlocked with the truck brake system to prevent fuel transfer before the truck is properly secured; remote-controlled, redundant liquid valves; storage vessel alarms to prevent overfill; and long drain lines for venting LNG vapour. Another safety feature used by some transfer systems is a pneumatic valve located at the tanker truck end of the flexible filling hose. A compressed air supply line from the fuelling station is hooked up to the flexible hose. The flow of compressed air is controlled by the operating mechanism of the station: the flow of air will be activated only when the correct mode to refill the storage tank is selected. When the system is ready, air flows and the valve opens, allowing the flow of fuel. Should the tanker truck suddenly move or drive off while the hose is still attached, the flow of air will be cut off, and the valve will shut, limiting the amount of LNG that is spilled and thus reducing the fire hazard.

The complexity of the fuel transfer arrangement creates the potential for leaks and spills through human error and equipment failure. One of the particular concerns is that the fuel transfer equipment goes through a continuous cycle of cool down to cryogenic temperatures and warm up to ambient temperature. This type of thermal cooling can create additional stresses on equipment and sealing devices, which could result in decreased reliability over time.

5.7.4 Fire hazards during storage

One of the major provisions at any LNG storage facility is the requirement to provide an impounding area surrounding the container to minimize the possibility of accidental discharge of LNG from endangering adjoining property, on important process equipment and structure, or reaching waterways. This requirement ensures that any size spill at a fuel storage facility will be fully contained and the risk of any fire damage will be minimized.

5.7.5 Other hazards

LNG presents a unique safety hazard among alternative fuels because of the potential exposure of personnel to cryogenic temperatures. Workers and consumers can receive cryogenic burns from direct body contact with cryogenic liquids, metals, and cold gas. Exposure to LNG or direct contact with metal at cryogenic temperatures can damage skin tissue more rapidly than when exposed to vapour.

The risk of cryogenic burns through accidental exposure can be reduced by the use of appropriate protective clothing and PPE. Depending upon the risk of exposure, PPE can range from loose-fitting, fire-resistant gloves and full face shields to special extra protection multi-layer clothing.

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9 Tom Drube, Chart Industries, Bill Haukoos, Chart Industries, Peter Thompson, UC Berkeley/Accenture, Graham Williams, GPWilliams Consulting; An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation
5.8 General safety information for LNG stations

In relation with the hazards described before, below there is a summary of the major hazards which is necessary to take into account by the LNG stations. For this reason, how it is shown in this section, it is important the training of all personnel related with this fuel (Driver, LNG station staff, etc.). In the end of the sub section there is information in relation with the emergency response.

A. General fire and explosion hazard

LNG is stored at pressures up to 16 bar, and when vaporized it is not explosive in an unconfined environment. Although a large amount of energy is stored in LNG, it generally is not released rapidly enough to cause the overpressures associated with an explosion. LNG vapours (methane) mixed with air are combustible but not explosive in an unconfined environment.

LNG spills or leaks will quickly vaporize since LNG has a boiling point of -161.5°C. Should a tank ever fail and a leak result, fire is possible, but only if there is the right concentration of LNG vapour in the air and a source of ignition. This concentration is a mixture containing 5% – 15% of natural gas in the air. Concentrations under 5% do not contain enough gas to burn, and concentrations over 15% do not contain enough oxygen to burn. This results in a fairly slow burn when any vaporized clouds of LNG are ignited in an open environment. Small leaks in enclosed spaces present a fire and explosion hazard because of the potential for methane to gradually build up to the necessary 5%-15% combustible concentration. LNG vapours also have a higher ignition point than either gasoline or diesel (540°C, 260°C, and 257°C, respectively).

LNG fires should be extinguished using dry chemicals only (Purple–K). Water fog or high-expansion foam can be used to suppress or contain fires. Water should not be sprayed directly into an LNG pool, since it will increase the rate of LNG vaporization.

B. Freeze burn hazard

Because LNG is a cryogenic liquid with a boiling point of -161.5°C, the liquid itself and any uninsulated hoses or containers will present a freeze burn or frostbite danger to exposed human skin.

C. Asphyxiation hazard

The components of natural gas (methane, ethane, and propane) are classified as “simple asphyxiates,” meaning they are not dangerous or poisonous in themselves, but can displace oxygen in enclosed environments. In outdoor environments, any LNG vapours will naturally disperse and rise into the atmosphere, posing little asphyxiation hazard. In enclosed spaces, LNG vapours from spills or leaks present an asphyxiation hazard, as they will displace oxygen. To alleviate this hazard, LNG vehicles are typically stored outside where vapours can dissipate. Any enclosed spaces such as workshops where LNG vehicles will be serviced should be equipped with methane detectors that are linked to automatically activate exhaust fans to clear the area in the event of a leak.

D. Spill hazards

Should a large amount of LNG be released into the environment, such as a spill from a truck or tank, the pool of liquid would quickly boil off and dissipate into the atmosphere\(^{10}\)\(^{11}\).

\(^{10}\) MSDS, LNG Material Safety Data Sheet
5.8.1 Driver training

Drivers who stop to refuel at LNG facilities must be properly trained. LNG fuelling is relatively simple, although it contains more steps than typical gas or diesel fuelling. The exact LNG fuelling equipment and procedure also vary slightly from station to station. Although many new LNG refuelling stations claim to be easy to use with “minimal or no training,” it still makes sense to ensure that drivers who stop are aware of the safety precautions and fuelling procedure for those specific stations. There are several possible options to ensure drivers are aware of proper LNG safety and fuelling procedures.

- Hands-on course

![Figure 5-2 Drivers undergo LNG refuelling training in Tiburg NL](image)

- Video training

![Figure 5-3 Video training setup in Commerce CA, USA](image)
5.8.2 Training of LNG station staff

Because LNG stations and dispensing equipment present unique operational and safety considerations, education and training will be important. The topics below discuss various user groups and education/training considerations for each.

A. General employee education

Every employee, from caretakers to executives, should receive some form of basic LNG education. This basic education would be designed as an overview of the major physical properties and safety information about LNG and fuelling stations in the form of either classroom training or an informational video.

B. Fuel handlers and station attendants

Because of the specialized storage and distribution equipment for LNG, each station installation should have the option of training the station attendants at that service area in the basic operation and maintenance of the LNG station equipment. Such training, if opted for, will be necessary for all station attendants.

5.8.3 Recommendations for training staff

In this sub-section will explain some recommendation that the LNG Blue Corridors project think that it should be implemented in a standard course relating to the safety issues in a LNG refueling station.

The content of this chapter has been provided by Gas Natural Fenosa which has prepared a detailed documentation to how must be operated the installations of the LNG refueling station.

This detailed information is the aim contents that training should have for a correct course in terms of security and safety.

Below there are the aim topics that should be explained in a standard course.

5.8.3.1 General concepts

Earlier to the LNG storage the user must required of the corresponding training and necessary information to operate with secure and safety.

LNG dispenser: The liquid natural gas is subministred in a lower pressure than 15 bars and temperatures below

A. Prohibitions

Around the dispenser smoking, used the phones and used the electronic devices were prohibited.

In any case

B. LNG dispenser

LNG subministration is by way of lower pressures than 15 bars and temperatures below -100 °C, these conditions means that the operator needs personal protective equipment.

It is necessary that during dispenser’s handling always it is used:
1. Cryogenic gloves: Protection hands in the case there is contact with low temperature elements.
2. Face shield: Protection of the face in the case there is contact with low temperature elements.
3. Antistatic clothing that fully covers your body: avoids contact with low temperature elements and possible static electrical discharges.
4. Protective footwear: that covers all of your calf and foot and avoids contact with low temperature elements.
5. Earth connection cable (Depending on the version): Control in a secure manner of possible electrostatic discharges to earth.
6. Liquid phase hose: Higher section, it introduces the LNG in a tank.
7. Gas phase hose: If it is necessary, it enable the gas evacuation in a control manner, to obtain the best filling in the short run.

Compatible connections DN25 (for liquid)

Topics must be verifying during the charge:

- Final pressure of the tank is the correct pressure of the tank specifications.
- Amount dispensed is the correct quantity specified by the customer.

By ambient and vehicle tank conditions it is possible to need some attempts.

For emergency situations the dispenser has a special pushbutton which stops immediately the activity. In this case it is necessary contact with the LNG station responsible and follows his instructions.

5.8.3.2 Security issues

Before the action of refueling LNG, the user must have the necessary training and information to perform the action with the maximum security and also to know how to react to any problem.

Around to the LNG dispenser smoking, usage of mobile phones and electronic devices are prohibited.

The usage of the LNG dispenser always requires the usage of the following protective equipment:

- Cryogenic gloves
- Face shield
- Antistatic clothing and protective footwear

A. Emergencies

In the case of an emergency (gas leak, fire or any situation that represents a risk for the persons or the installation) the user has pushbuttons in order to activate the emergency stop of the refueling. If there is no emergency mustn’t be activated the emergency stop.

Once the emergency stop is activated, the user mustn’t reset the pushbutton, the user is required to inform immediately to the responsible of the installation and to follow the instruction, even if the activated has been by error.

All the emergency case will be recorded and with it is activated the Self-protection Plan according with the actual regulations.

B. Prohibited actions during the LNG refueling
- Tanks that have not previously been conditioned to LNG or, in the case, that have been completely emptied (leaks or damaged), it is necessary the technical assistance of the filling station.
- Tanks with around or higher pressures than the security pressure (view in the owner manual), always it is necessary that the pressure was lower than 15 bars (except special tanks), it must reduce previously the pressure.
- Tanks with defects, dirty, wet, with leak or any anormal aspect of the connections. The humidity will be eliminated with pressure air or blotting paper.
- Tanks have suffered some damage and which have not been verified and certified as approved by specialist.
- If the installation have damage in the connections (hoses and earth connections), there is any leakage or the indicators shown any anomalies. It is necessary contact with the responsible of the refilling station in situ or with the assistant telephone (in secured area)

**C. Refueling**

- Park the vehicle in front of the dispenser oriented towards it, the correct distance is which enables approximate the hoses without forcing them and movement without tripping.
- Check that the dispenser is activated and the hoses don’t have leaks. If the vehicle pressure is high (> 13 bars) it is necessary connect only the return hose and then it is checked that the pressure increase (<12 bars) before follow with the operation of refilling.
- Select the the dispenser with the card and select the LNG option.
- Use the PPE (gloves, face shield, clothing and proper footwear), connect the earth connection to the chassis of the vehicle.
- Remove the protective covers and check that the vehicle connections are clean and without humidity. Use compressed air or blotting paper to guarantee that the connections are dry. Select in the dispenser the type of charge.
  - Control the state of the pressure.
- Desconnection of the hoses and the earth connection in reverse form to the connection.
- Put the protective covers.

*Figure 5-4. Hose connection in the vehicle*
5.8.4 Emergency responders

Because LNG has different properties from traditional gas and diesel fuels, local emergency responders around each station will need to be educated in how to respond to any potential emergencies at the LNG station or at the scene of LNG vehicle accidents. This process will vary significantly depending on the locality of each station.\footnote{ANGA, America’s Natural Gas Alliance, TIAA U.S. and Canadian Natural Gas Vehicle Market Analysis Liquefied Natural Gas Infrastructure: Final Report}

The primary purpose of the Emergency Plan is to share basic information with emergency responders. The plan provides general guidance to emergency responders and typical actions that employees use for mobilization of personnel and resources, while continuing operation of facilities during an emergency in order to keep the public safe and minimize gas service interruptions.

5.8.4.1 General guidance: operational examples\footnote{SOURCE: http://www.northernnaturalgas.com/safety/pa/Pages/EP.aspx}

Emergency responses to LNG incidents generally involve a spill or fire. For spills inside LNG facilities, the product will usually be diverted to containment impounding pits. Vapours are produced and may be in their flammable range. The recommended methods for dealing with an unignited and contained LNG spill include high-expansion foam and/or water curtains. High-expansion foam reduces the vaporization, thereby reducing the vapour cloud. It cannot, however, completely prevent vaporization. Initially, it may increase the rate, since the foam adds heat to the LNG. However, once this vapour surge is dispersed, the foam reduces vaporization. Tests using high-expansion foam have shown a 60% vapour reduction. Using non-aspired or low-expansion foams does not significantly reduce

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure_5-5_Hose_disconnection_in_the_vehicle}
\caption{Hose disconnection in the vehicle}
\end{figure}
vaporization and should not be used, water curtains can be used to control the vapour cloud. Do not allow runoff to come in contact with the LNG pool, because it will increase the vaporization rate.

For burning pool fires, the use of high-expansion foam, dry chemical (such as potassium bicarbonate), and exposure protection are recommended tactics. For complete extinguishment, only dry chemical will be effective. (Portable high-expansion foam generators may not be effective, since radiant heat may not allow the proper positioning of the generator). High expansion foam should be used to reduce vapours and radiant heat, the LNG will continue to burn through the foam and can either be left to burn, consuming the fuel, or extinguished using dry chemical. A three-foot blanket of foam should be maintained on top of the LNG. Exposed equipment can be protected with water streams.

Jet fires may occur in pressurized LNG vaporizers or the unloading during tanker operations. A jet fire may cause severe damage, be confined to a localized area, and would be limited by safety systems that would be limited by systems that would stop the flow.¹⁴

Emergency responders such as police, fire, and others are often the first to learn of an incident involving facilities. The following actions are offered as a guide:

1. Secure the area and control access to the site. Traffic barricades or re-routing may be required
2. If the LNG is leaking but not burning, avoid doing anything that may ignite it. Eliminate ignition sources such as vehicles, cell phones, pagers, two way radios, electrical equipment, switches, door bells, flashlights, static electricity, cigarettes, etc.
3. Evaluations or sheltering in place may be necessary
4. Be aware of weather conditions such as lighting storms and stay upwind
5. If the LNG is burning, control secondary fires but not attempt to put out pipeline fires
6. Do not operate pipeline valves
7. Provide medical assistance if safe to do so
8. Others deriving to the safety training

6 Safety conditions to the LNG Value Chain

In the last years the LNG market has had a growing; in order to continue with this increase and to convert in a typical fuel of European long transport it is necessary to do a study of the possible risks of the LNG value chain.

In this deliverable the risk that we treated is the risk associated to safety and security, and in this section, in particular, the risk in safety and security related with the LNG value chain.

These risks can be, in general:

- Political and regulatory: The delay in the regulation of the market, technical, gas quality, etc. could mean a problem in a LNG as competitive fuel.
- Safety and security: prevention of accidents and intentional acts of terrorism is a key to ensure the market of the LNG for the industry, transport and future consumers.
- Environmental impact: The gas is considered a friendly fuel with the environmental issues, the LNG have to defend this position.
- Public perception: as the LNG still is much understood for the public, it is necessary that study how it do known so there are no misunderstandings and have become a regular fuel.
- Reliability of new technology: As competition grows in the LNG market, companies are leaving tried and true traditional technologies for innovative methods and devices, in order to reduce costs and improve flexibility, safety, and security. Technological improvements, however, can require extensive training costs and can introduce unforeseen problems, creating an uncertainty about reliability that many operators are not willing to accept.
- Project management: Project risk captures the various risks associated with post-approval construction and operations, namely delay and cost overruns. While developer cost overruns have been widely publicized in projects like Sakhalin II, the reality is that almost every new upstream project is feeling the crunch. Some of the risks are simply inherent in complex industrial design, but the rush to build upstream capacity is exacerbating these risks.
- Competence and quality assets: The demand for highly skilled employees outstrips the supply across the energy industry, nowhere more so than for contractors with LNG experience and capabilities. Considering the additional strains that globalization places on the market, early signs of quality control problems are becoming apparent.
- Harsh environments: As demand for natural gas increases, the industry increasingly needs to draw upon difficult-to-obtain reserves; it also needs to consider regassification terminals in more challenging locations. This requires new technology, unprecedented budgets, and new ways of thinking.

The LNG industry has always paid attention to safety management. This has been handled through LNG specific design codes onshore, Class notation for vessels, the SIGTTO guidelines, and strict procedures for operation.

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25 SOURCE: DRAFT DEVELOPING SAFE AND RELIABLE LNG SUPPLY CHAINS IN THE NEW GLOBAL ENVIRONMENT: EXPERIENCE AND LESSONS FROM SIX CONTINENTS
Different regions apply distinctively different safety regimes for avoidance of unintentional events, with the greatest divide being between consequence management and risk-based management. A consequence-based approach for accidents based on NFPA 59A is applied in the U.S. and is common in Asia. The NFPA approach has the benefit of requiring less analysis than the risk-based approach, and may be easier to communicate to the public. By focussing on worst-case consequence scenarios for accidents while disregarding the probability of occurrence, however, this approach limits the ability to assess the effectiveness of project-specific measures aimed at reducing the likelihood of events.

A risk-based approach begins with assessing the probability that the subject risk, or failure, will occur and how such probability can be best reduced by mitigating factors; consequences are not ignored, but are measured relative to the level of mitigated risk. Such an approach is embodied in EN1473, which is widely applied in the EU for safety. The processes differ slightly from country to country, but they all apply a risk-based approach. Russia has begun developing LNG legislation that also will be risk-based. The Zebrugge terminal and Qatar Gas used risk assessments to document that Qflex-size carriers can dock at the terminal without increasing the risk to public. In fact, the risk may be reduced when comparing equal import levels.

Canada has a risk-based approach defined in their legislation, but it lacks formal acceptance criteria, and Canadians also look towards NFPA for plant layout. The risk-based approach requires competence and tools for performing state-of-the-art risk analysis. The Rabaska project successfully utilized the risk-based approach to develop a buried unloading line, minimizing the hazard to public. This design improvement would not have been supported if only consequences were assessed without assessing the probability.

African countries generally lack defined legislation for LNG. Instead, the engineering contractor typically uses whichever international approach it has the most experience in applying.

The risk calculus for security, the avoidance of intentional acts of terrorism, involves different factors and considerations than when dealing solely with safety issues. There are no experiences or accepted standards for assessing the risks of an act of sabotage. Conventional wisdom post 9/11 offers that this risk correlates to the potential for the loss of human life (though this approach ignores threats of economic terrorism against energy infrastructure, as the rebels have threatened in Nigeria). In densely populated areas, for example, this approach could lead to a conservative use of a consequence-based model, because the tolerance for risk is so low.

The United States has sought to develop the science and the regulatory structure to assess and mitigate the risks and consequences of terrorist acts targeted at LNG vessels and facilities. The foundation of the approach are studies by the federal government laboratories, Sandia, to determine the potential (i) hole sizes in an LNG vessel as a result of various possible acts of terrorism (which are classified), and (ii) the consequences of LNG spills on water as a result of such hole sizes. While Sandia concludes that the risk of a successful act of terrorism against an LNG vessel is low, it released detailed studies of assessing the risks of thermal radiation and vapour zones as a result of an LNG spill on water caused by a breach in the vessel tanks. Most significantly, the potential devastating fire resulting from such a spill, referred to as Sandia “zone 1,” can extend out to 500 meters.

Sandia has become the main reference for U.S. authorities seeking to impose operational conditions on LNG vessels and facilities. The U.S. Coast Guard, which is primarily responsible for ensuring safety and security on U.S. waterways, has adopted Sandia as an integral part of its NVIC 05-05, the process by which the agency determines waterway suitability for the transit and berthing of LNG vessels to
receiving terminals. The process calls for the developer to submit a Waterway Suitability Assessment (WSA) based on rigorous analysis of all relevant factors. The Coast Guard ultimately issues a Waterway Suitability Report that, in turn, will be incorporated into the LNG Operations Plan for that waterway, which sets forth the conditions for secure transit operations. The process inherently integrates both a risk assessment of possible terrorist acts against the vessel and, as noted, the potential consequences of such acts.

Since security has become ever more intertwined with government risk management companies have come to realize they will face rigorous safety and security review especially downstream. Since safety and security drive public perception and project approval, especially in the United States, it is critical not only to a project’s profitability, but to its very existence.
7 Assessment of relative safety in the LNG transport fuel supply chain

After the information that explained in the deliverable until now, it is possible to do an assessment of safety in vehicle transportation, comparison to other fuels, safety in LNG stations and safety in vehicle storage tank.

7.1 Safety assessment of vehicle transportation

The movement of truckload volumes of transport fuel, using the public roads and highways raises a number of safety concerns due to the relatively large volumes of fuel in one vehicle. This section aims to show the risk related with this issues doing an exhaustive analysis of the risks, and comparing them between the different fuels currently used. In the following subsections tables with the evaluating of these risks are shown in the following way:

First of all, it is shown the risk which is studied the possibility of relative consequence and relative probability of event (both cases with its level of risk) and finally it is evaluated the level of the risk which has shown.

The evaluations of the levels are expressed in the following way:

Higher: greater relative risk due to potential higher consequences, or higher probability of the event.

Similar: similar relative risk to use of other fuels

Lower: Lower relative risk due to lower consequences or lower probability of the event

7.1.1 Safety risks

Tanker truck risks largely focus on either a high-impact crash or a mechanical failure leading to the release of the cargo (up tp 13,000 gallons of LNG) into a public environment. The consequences could be a cryogenic LNG spill which may lead to injuries and property damage, a fire potentially causing injuries and property damage, a fire potentially causing injuries and property damage, or a vapour cloud fire.

Potential causes of loss of containment include:

- Tank/piping failure due to impact
- Tank/piping failure due to overpressure
- Material failure due to corrosion
- Material failure due to brittle fracture
- Piping failure due to vibration and/or thermal fatigue
- Operator error (e.g. leaving a valve open)

Multiple safeguards are employed to prevent those causes from resulting in a loss of containment. These include:
Mechanical design requirements are specified in Codes and Standard. Tank designs are particularly robust. LNG tankers are double-walled with insulation and structural supports in the vacuum layer between walls. This double layering maintains LNG at cryogenic temperatures and also provides additional protection against punctures and weakening due to external fire exposure.

Pressure relief devices are placed on all sections of storage and piping equipment where LNG maybe held. These limit equipment operating pressure at safe levels and will safely vent gas if an overpressure occurs.

Inspection and maintenance. Regular inspections of safety devices and loading/unloading hoses are specified.

Operating procedures and training. This covers not only the operation of the LNG equipment, but also safe driving practices.

7.1.2 Safety analysis and comparison to other transport fuels

LNG tanker trucks have decades of safe operating experience and it is also necessary take into account that the potential for highway accidents or crashes is similar to that of tankers hauling diesel or gasoline.

If it is compared the transport of LNG with diesel or gasoline, the LNG has advantages like in the case of physical rupture, since the tanks are significantly stronger than those carrying traditional liquid fuel and are also double-walled.

If it is studied the record to date compared to similar impacts for diesel trucks, these last cases have caused significant spills.

This lower probability of a significant incident must be compared to the potential damage of an LNG spill compared to diesel or gasoline. In both cases, a large fire is the most realistic danger in a major collision. In the case of LNG, the additional risk relates to the possibility of an explosive event, if the evaporating gas has encountered some form of containment.

Below it is shown a table with the evaluation of possible risks, as it has explained in the introduction of the section.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Relative consequence</th>
<th>Relative probability of event</th>
<th>Risk level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large spill from road collision</td>
<td>Higher:</td>
<td>Lower:</td>
<td>Similar</td>
</tr>
<tr>
<td></td>
<td>• Fire injury to people and property</td>
<td>• Evidence demonstrates extreme difficulty in rupturing tank to the level required for a large scale incident</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cryogenic burns to people in contact with cold vapours/liquids</td>
<td>• Requires confinement to create risk of explosion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Risk of explosion if the gas is confined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank overpressure</td>
<td>Similar:</td>
<td>Lower:</td>
<td>Lower</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.2 Safety assessment of bulk delivery and fuel storage at fuelling stations

The function of the refuelling stations are similar, regardless of the fuel. The only variations are related to the location, nature and volume of fuel stored and the risks around fuel dispensing. In comparison with the LPG fuel, the LNG can be viewed as more safe because the LNG spills are able to dissipate it in the air relatively in a way more safety than LPG, due to the LNG vapours warming, and becoming more buoyant than LPG.

But in comparison with the diesel and gasoline it is necessary to take into account more restricted measures.

The latest regulations related with the LNG vehicular fuel systems and refuelling sites require a containment system to catch spills and establish separation distances for any buildings or properly lines.

The relative danger of direct contact with LNG compared to diesel and gasoline also increases safety requirements around dispensing pumps. Therefore LNG systems are interlocked and contained such that LNG is never in contact with the atmosphere during refuelling as is the case for diesel and
gasoline refuelling. Therefore LNG should not come in direct contact with people, property or sources of ignition unless there is a significant system failure.

Potential causes of loss of containment or spills include:

- Tank/piping failure due to impact
- Tank failure due to loss of strength (caused by fire exposure)
- Tank/piping failure due to overpressure
- Material failure due to corrosion
- Material failure due to brittle fracture
- Piping failure due to vibration and/or thermal fatigue
- Operator error (e.g., leaving a valve open)
- Accident, operator error or equipment malfunction during fuel delivery and unloading
- Collision with on-site storage tank, dispenser
- Mechanical failure in tank, tanker offloading pumps, or refuelling equipment leading to vapour leak or LNG spill
- Operator error or equipment malfunction during trailer unloading
- Underground leaks migration through electrical ducts or drainage pathways into a neighbouring building (underground vapours find the path of least resistance which sometime results in explosion hazards into the buildings – has occurred in industry at CNG refuelling facilities)

Multiple safeguards are employed to prevent those causes from resulting in a loss of containment. This includes:

- LNG storage containers are double-walled with insulation in the vacuum layer between walls. This double layering maintains LNG at cryogenic temperatures but also provides additional protection against punctures
- Employees performing tanker fuel delivery to site wear appropriate protective safety equipment and follow a range of safety procedures to minimize risk
- Pressure relief devices are placed on all sections of storage and piping equipment where LNG maybe held. These allow safe release of any pressure build-up beyond acceptable levels
- Site-design standards have clear requirements for secondary containment. Sites must have dikes in place to contain spills up to full volume of the largest tank on-site
- Codes set a stand-off distance for other buildings of 50 ft for storage tanks with capacities between 15,001 and 30,000 gal and 75 ft for storage tanks with capacities between 30,001 to 70,000 gallons. Shorter distances are permitted with the approval of the Authority Having Jurisdiction
- LNG Dispenser separation distance of 20 ft from other fuel dispensers
- Detection systems for methane, fire and cryogenic temperatures are required throughout the site and particularly in locations where gas could accumulate
- Dispensing pumps have a number of cut-off switches to ensure LNG will only dispense when the pump nozzle is correctly attached to the tank
- Dispensing is currently only performed by personnel who have received training in refuelling and LNG safety
- Rated impact protection for all above ground equipment design based upon site risk assessment
- Underground electrical conduit seals prior to building entrance from underground piping leak
- Additional considerations - Operator checks of customer vehicles for certification documentation or tag of receiving cylinders. (Not a code requirement)
- Additional considerations - For public locations where LNG has minimal daily on-site, provide integrated emergency shutdown of all site operations, offload tanker pumps, and on-site pumping and ESD valves when a leak is detected by gas detectors on site or by push of any ESD button on site. – Not a Code Requirement
- Auditable routine preventative maintenance and inspection in accordance with codes and manufacturers guidelines

7.2.1 Safety analysis and comparison to other fuels

Safety considerations for LNG stations differ from those associated considerations with pipeline-supplied CNG stations. The LNG stations will hold a greater inventory of natural gas in the station at any time than CNG stations; however the LNG is stored more stably at low pressure in double-walled tanks rather than the high-pressure tanks in which CNG is stored.

The risks of LNG storage at LNG refuelling sites are inherently higher since these tanks are typically above ground and gasoline and diesel tanks are typically underground, but comparable to LPG storage which is also above ground. These risks are mitigated through additional safety features such as increased separation distances (relative to gasoline and diesel), spill containment requirements, and methane gas detectors. Dispensing risk is similar to the process for CNG with both closed systems requiring a more secure fitting between the tank and the nozzle than gasoline or diesel and having similar risks relating to a seal failure (one releasing a high pressure jet of flammable gas, the other a low pressure flow of cryogenic liquid) which require cut-off devices.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Potential scale of damage</th>
<th>Probability of event</th>
<th>Risk level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large spill during bulk delivery</strong></td>
<td>Higher than diesel and gasoline:</td>
<td>Lower:</td>
<td>Similar</td>
</tr>
<tr>
<td></td>
<td>• Release of large volume of LNG from either tanker or site storage</td>
<td>• Redundant backflow prevention valves at tank inlet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cryogenic burns to people in the immediate vicinity</td>
<td>• Highly trained personnel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Potential ignition of a large vapour cloud causing large fire</td>
<td>• Containment mitigates risk of spilled LNG compared to a diesel spill</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Similar to LPG</td>
<td>• Numerous cut-off valves on both sides of transfer Procedures in place, such as turning off possible ignition sources while LNG vapours dissipate</td>
<td>Lower than LPG</td>
</tr>
<tr>
<td><strong>Small spill during</strong></td>
<td>High:</td>
<td>Low:</td>
<td>Similar</td>
</tr>
<tr>
<td></td>
<td>Cryogenic burns to person</td>
<td>• Safer dispensing</td>
<td></td>
</tr>
</tbody>
</table>

*Table 7-2 Safety analysis and comparison with other fuels – Fuel storage*
### Dispensing

- dispensing

- mechanism than diesel: sealed transfer, cut-offs. 
  Trained personnel in protective attire where appropriate.

#### Site large storage tank spill

<table>
<thead>
<tr>
<th>Higher:</th>
<th>Similar:</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Release of large volume of LNG site storage</td>
<td>• Above ground tank, increasing exposure to impact</td>
<td></td>
</tr>
<tr>
<td>• Cryogenic burns to people in the immediate vicinity. Potential ignition of a large vapour cloud causing large fire</td>
<td>• Highly trained personnel limit risk of error Site measures mitigate potential damage of spilled LNG e. g. dikes.</td>
<td></td>
</tr>
</tbody>
</table>

#### Small gas leak from equipment

<table>
<thead>
<tr>
<th>Similar:</th>
<th>Lower:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Leak from equipment connected to or close to storage tanks risks escalation of damage.</td>
<td>Would require failure of multiple gas sensors on site to coincide with leak event. Requires conduit penetration seal offs.</td>
</tr>
<tr>
<td>• Leak if undetected cloud from sufficient vapour cloud for fire. Leak from underground piping risk intrusion of vapours into nearby building through conduit.</td>
<td></td>
</tr>
</tbody>
</table>

### 7.3 Safety assessment of vehicle fuel storage tanks

Compared to a tanker truck unloading, the potential hazard for a vehicle refuelling is limited because of the smaller LNG volume involved in a single incident. Despite their smaller size, LNG fuel tanks can, however, produce significant spills in public locations. Vehicle fuel tanks are also more at risk of incidents than tankers due to the broader range of applications and risk of less well-trained personnel performing monitoring and maintenance in the field. The major safety concerns are similar to those of tanker trucks although the risk probability and scale of damage are significantly different.

Potential causes of loss of containment or spills include:

- Tank failure due to impact
- Tank failure due to loss of strength (caused by fire exposure)
- Tank failure due to overpressure
• Material failure due to corrosion
• Material failure due to brittle fracture
• Failure due to vibration and/or thermal fatigue
• Fitting on vehicle either defective, damaged in earlier refuelling and not repaired, not compatible with the fuelling station nozzle, covered by dirt and/or ice or not constructed for LNG use

7.3.1 Mitigating technologies, codes and standards
• LNG cylinders are subjected to standard safety tests that CNG cylinders undergo, including burn, crash, and gunshot tests
• LNG tanks are pressure vessels that are much stronger than conventional diesel-fuel tanks, making a penetration of an LNG tank less likely than for a similarly mounted diesel tank
• Sealed, pressurized system less prone to operator caused fuel spills than gasoline or diesel refuelling may cause
• Fuelling nozzles or pressure relief valves vent evaporating LNG to manage vehicle tank pressure (without necessarily venting to atmosphere)
• Sensors on the vehicle can identify methane leaks or temperature changes allowing shutoff
• Detailed operating codes are in place around use of LNG vehicles and procedures should a risk alert be raised
• As with CNG vehicles, strict codes for maintenance and monitoring of tanks exist. With CNG, a more publically-used fuel type, the majority safety incidents relate to failures due to tank installation or tank safety monitoring

7.3.2 Safety analysis and comparison to other fuels
LNG vehicle fuel tanks are considerably more robust than diesel or gasoline fuel tanks. They are also relatively less at risk of impact damage than a CNG tank due to the high pressure contained within a CNG tank and its single-walled container.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Potential scale of damage</th>
<th>Probability of event</th>
<th>Risk level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spill from road collision</td>
<td>Higher:</td>
<td>Lower:</td>
<td>Similar</td>
</tr>
<tr>
<td></td>
<td>• Cryogenic burns to people within immediate vicinity</td>
<td>• Difficulty in rupturing tank to the level required for a large scale incident</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gas burning people and property</td>
<td>Pressure release devices will safely manage pressure build-up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Diesel presents similar risk</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Possibility of explosion in certain situations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating of tanker contents</td>
<td>Higher:</td>
<td>Lower:</td>
<td>Similar</td>
</tr>
<tr>
<td></td>
<td>• Fire could lead to explosive pressure build-up if PRD system is somehow unable to relieve pressure</td>
<td>• US codes on tank insulation and pressure releases devices make a BLEVE unlikely</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Event must coincide with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure of a pressure release devices (PRD)</td>
<td>Higher:</td>
<td>Lower:</td>
<td>Lower</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>---------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>Failure to vent gas cloud lead to a dangerous pressure build-up which in extreme cases could rupture violently</td>
<td>Failure to detect a small fuel leak</td>
<td>Would require the failure of both PRD concurrently</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure to detect a small fuel leak</th>
<th>Higher:</th>
<th>Lower:</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar:</td>
<td>Lower:</td>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>• An undetected leak could cause asphyxiation in an enclosed space or fire causing burns and damage.</td>
<td>• To be significant, would require the combined failure of the storage tank causing the leak and the methane sensors detecting the gas</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Venting of vapour from vehicle tank</th>
<th>Higher:</th>
<th>Higher:</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher:</td>
<td>Higher:</td>
<td>Higher</td>
<td></td>
</tr>
<tr>
<td>• LNG vehicle is expected to be stored outside or in facilities designed to collect and discharge methane vapour releases. Garage roofs would safely gather the lighter-than-air vapour and ventilation to vent diluted gas. LNG vehicles should be stored in well ventilated areas, or outside, where gas releases cannot build up in enclosed spaces.</td>
<td>• Venting from pressure relief devices on vehicles parked for prolonged periods is expected. The tanks could be emptied or the venting gas reclaimed or catalytically burned if a commercial vehicle is parked for prolonged periods.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8 Guidelines and standards for refuelling

8.1 Spain

There is no uniform LNG regulation. Based on national and local standard for CNG fuelling stations as UNE 60631 - CNG stations for motor vehicles- and UNE 60210 - Satellite plants Liquefied Natural Gas (LNG).

Prevention of fire: control of the CNG buffer cylinders for LCNG fuelling stations and of cryogenic storage systems shall be carried out by certified bodies as specified by UNE 60210 and UNE 60312.

8.2 The United Kingdom

UK is working from the ISO standards: ISO/DIS 16924, and other existing standards such as NFPA 52 and BS EN 13645 - Installations and equipment for liquefied natural gas (for site safety requirements, LNG storage tanks and prevention of fire)

The British Compressed Gas Association (BCGA) has recently produced a code of practice, BCGA CP41, The design construction, maintenance and operation of filling stations for gaseous fuels (2014). Section 3 of the BCGA CP41 provides a useful summary of the UK legislation around sites such as LNG filling stations, explaining the purpose of the key DSEAR, COMAH and PSSR regulations.

Others:
- LNG storage tank: EN 13458.
- Safety distances: IGEM UP5
- Inspections: Pressure Systems Safety Regulations (2000) - PSSR
- Hazardous areas are subject to EN 60079 - Explosive atmospheres - Part 11: Equipment protection by intrinsic safety.

8.3 The Netherlands

Standards are based on PSG 33-1:2013.

Regarding the filling process, the LNG storage tank shall be designed according to NEN-EN 13645 that ensures that filling of the LNG storage tank stops automatically on reaching the maximum filling capacity.

Prevention of fire: a fire extinguisher shall be suitable for fire classes B and C according to NEN-EN 2 and also meet the requirements included in NEN-EN 3. The characteristics, performance requirements and test methods for the fire extinguisher are based on NEN-EN 3-7, which shows that it is suitable for fighting fire classes B and C. Fire extinguishers shall have an extinguishing capacity of at least 43A / 233B according to NEN-EN 3-7. Fire extinguishers shall be protected from or resistant to the effects of the weather.

8.4 Sweden

8.5 Portugal

There is no uniform LNG regulation. The temporary requirements are those contained in the ISO/DIS 16924 - Natural Gas Fuelling Stations, LNG Stations for fuelling vehicles.

Prevention of fire: explosion protection measures are mandatory in accordance with EN 1127-1 – Explosive atmospheres.

Equipment and components shall be designed in accordance with requirements for Explosion Group IIA and temperature class T3 as defined in IEC EN 60079-0 - Explosive atmospheres - and applicable standards for non-electrical equipment for use in potentially explosive atmospheres (e.g. EN 13463–1 - Non-electrical equipment for potentially explosive atmospheres).

The Portuguese legislation: Decreto Lei 1270 /2001, 8 Nov, article 49 – Dispensers is applicable regarding safety in dispensers.

8.6 Other European countries

ITALY:

There is no uniform LNG regulation. It is based on national and local standard for CNG fuelling stations as Ministry Decree No.28 and D.M 28 June 2002 – S.O. G.U. No 161 regarding the NG delivering.

Site safety requirements are based on EN 13645 - Installations and equipment for liquefied natural gas and Italian Guideline for LCNG station.

A technical guide published by the Italian Ministry of Interior (Dipartamento dei vigili del fuoco, del soccorso pubblico e della difesa civile) this year (2013), includes the measures in prevention of fire relating to the delivery of LNG to cryogenic tanks used in fuelling stations for CNG vehicles.

AUSTRIA:

LNG legislation will be based on the standards for CNG refuelling station (ÖVGW 97 (2005) - NGV Filling Stations - Design, Production, Installation and Operation of NGV Filling Stations).

HUNGARY:

They are elaborating regulations in parallel for the future projects according to the ISO/DIS 16924 - Natural Gas Fuelling Stations, LNG Stations for fuelling vehicles.
GREECE:

Some national regulations for CNG stations will be applicable to LNG refilling stations as N.3850/2010 – Health and safety at work.

SLOVENIA:

For obtaining building permit the investor has to present Fire Safety Study and Explosion Protection Document, which are based on the following standards:

- ISO/DIS16924 - Natural gas fuelling stations - LNG stations for fuelling vehicles;
- ISO/DIS16923 - Natural gas fuelling stations - CNG stations for fuelling vehicles;
- SIST EN 1160 - Installations and equipment for liquefied natural gas;
- SIST EN 13458 - Cryogenic vessels;
- SIST EN 13480 - Metallic industrial piping;
- SIST EN 13645 - Installations and equipment for liquefied natural gas - Design of onshore installations with storage capacity between 5 t and 200 t;
- DVGW - Arbeitsblatt G 651 - Richtlinien für Planung, Bau, Errichtung, Prüfung, Inbetriebnahme und Betrieb von Erdgastankstellen;

GERMANY:

There is no uniform LNG regulation. Based on the ISO/DIS 16924 for LNG fuelling stations, the Dutch standard for LNG fuelling stations PGS 33-1:2013 – Dutch regulation for LNG station, DIN EN 13645 - Installations and equipment for liquefied natural gas, and DVGW G215 - LNG for industrial installations.

FRANCE:

Site safety requirements are based on French regulation ICPE 1412 – liquefied flammables gas (manufactured storage tanks), ICPE 1413 - Natural gas or biogas pressure (tank filling systems), and ICPE 1414 - Liquefied flammable gases (filling plant or distribution).

CROATIA:

None

BELGIUM:

There is not yet a regulation on national or regional level. However, there is an initiative to start this regulation in Flanders.
9 EU regulatory framework

9.1 European standards

European Committee for Standardisation (CEN)

CEN is a private non-profit organisation whose mission is to “contribute to the objectives of the European Union and European Economic Area with voluntary technical standards which promote free trade, the safety of workers and consumers, interoperability of networks, environmental protection, exploitation of research and development programmes and public procurement.”

In Europe, the codes and regulations specific to LNG import facilities include:

- **European Union Seveso II Council Directive** 96/82/EC of 9 December 1996 - Control of Major-Accident Hazards involving Dangerous Substances. For the European Union all operation and maintenance activities are under the control of a Safety Management System required by Directive Seveso II 96/82/EC. This pronouncement includes a revision and extension of the scope of Seveso I, the introduction of new requirements relating to safety management systems, emergency planning and land-use planning and a reinforcement of the provisions on inspections to be carried out by Member States.
- **EN 1473**: “Installation and equipment for LNG – Design of onshore installations” for storage capacities over 200 tonnes. The European code **EN 1473** is based on a risk assessment approach with fewer explicit prescriptive standards, compared to US regulations or US standards.
- **EN 1160**: “Installation and equipment for Liquefied Natural Gas – General characteristics of liquefied natural gas” This standard contains guidance on properties of materials that may come in contact with LNG in the facility.
- Additional codes include: **EN 146201** (“Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and -165°C”), **EN 1474** (“Installation and equipment for LNG – Design and testing of LNG loading/unloading arms”), **EN 1532** (“Installation and equipment for LNG – Ship to shore interface”); and **EN 13645** (“Design of onshore installations with a storage capacity between 5 tonnes and 200 tonnes”).

Applying their own regulations derived from the Seveso II Directive, national authorities of each European country have the responsibility to issue a certificate to the facility and are the lead agency for review of environmental and safety concerns, including public comment meetings and review procedures.

The following US standards may also be applied in Europe:

- NFPA 52 – for safety in CNG and LNG fuel systems and fuelling facilities;
- NFPA 59A - Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG); and
9.2 End user experiences

9.2.1 Spain

Spain is undoubtedly the pioneer in Europe of LNG as fuel. Indeed, in 2000, the Spanish transporter HAM, purchased 10 truck tractors from the USA powered by liquefied natural gas, making them the leader in its use for transport in Europe.

Nowadays, this country features over 16 fixed stations, delivering LNG and L-CNG. Other stations are under developments within GARnet TEN-T EA project and FP7 LNG Blue Corridors Projects.

Public and private refilling stations are stated below:

<table>
<thead>
<tr>
<th>No.</th>
<th>Refuelling Station</th>
<th>Natural Gas Fuel</th>
<th>Owner and Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abrera, Barcelona</td>
<td>LNG &amp; L-CNG</td>
<td>HAM</td>
</tr>
<tr>
<td>2</td>
<td>Castellón de la Plana, Castellón</td>
<td>LNG &amp; L-CNG</td>
<td>MONFORT</td>
</tr>
<tr>
<td>3</td>
<td>Torremocha del Campo, Guadalajara</td>
<td>LNG &amp; L-CNG</td>
<td>HAM</td>
</tr>
<tr>
<td>4</td>
<td>Olaberría, Guipuzco</td>
<td>LNG &amp; L-CNG</td>
<td>VICUÑA</td>
</tr>
<tr>
<td>5</td>
<td>Lleida</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>6</td>
<td>Tarragona</td>
<td>LNG &amp; L-CNG</td>
<td>HAM</td>
</tr>
<tr>
<td>7</td>
<td>Alovera, Guadalajara</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>8</td>
<td>Vitoria, Alava</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>9</td>
<td>Valencia</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>10</td>
<td>San Isidro, Alicante</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>11</td>
<td>Motilla del Palancar, Cuenca</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>12</td>
<td>Zaragoza</td>
<td>LNG &amp; L-CNG</td>
<td>VIA AUGUSTA</td>
</tr>
<tr>
<td>13</td>
<td>Gallarta, Bilbao</td>
<td>LNG</td>
<td>HAM</td>
</tr>
<tr>
<td>14</td>
<td>Tres Cantos, Madrid</td>
<td>LNG &amp; L-CNG</td>
<td>HAM</td>
</tr>
<tr>
<td>15</td>
<td>Sevilla</td>
<td>LNG</td>
<td>HAM</td>
</tr>
<tr>
<td>16</td>
<td>Málaga</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>17</td>
<td>Sª Perpetua de Mogoda, Barcelona</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>18</td>
<td>Girona</td>
<td>LNG &amp; L-CNG</td>
<td>HAM</td>
</tr>
<tr>
<td>19</td>
<td>Rivas, Madrid</td>
<td>LNG &amp; L-CNG</td>
<td>GNF</td>
</tr>
<tr>
<td>20</td>
<td>Vitoria, Alava</td>
<td>LNG</td>
<td>EDP NATURGAS</td>
</tr>
</tbody>
</table>

16 GHIGNL; Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations, Information Paper No. 4 – Operational Integrity, Regulations and Industry Organisations

9.2.2  The United Kingdom

With 9 LNG refilling stations, the United Kingdom is a steadily developing LNG country in Europe.

No data are available about L-CNG refilling stations.

Some public and private refilling stations are stated below:

<table>
<thead>
<tr>
<th>No.</th>
<th>Refuelling Station</th>
<th>Natural Gas Fuel</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nottingham</td>
<td>LNG</td>
<td>T. Baden Hardstaff Limited</td>
</tr>
<tr>
<td>2</td>
<td>Bristol</td>
<td>LNG</td>
<td>Moto Severn Bridge Services</td>
</tr>
<tr>
<td>3</td>
<td>Nerston</td>
<td>LNG</td>
<td>Chive Bellshill</td>
</tr>
<tr>
<td>4</td>
<td>Castleford</td>
<td>LNG</td>
<td>Chive Castleford</td>
</tr>
<tr>
<td>5</td>
<td>Droitwich</td>
<td>LNG</td>
<td>Chive Droitwich</td>
</tr>
<tr>
<td>6</td>
<td>Flamstead</td>
<td>LNG</td>
<td>Watling St. Station</td>
</tr>
<tr>
<td>7</td>
<td>Lymm</td>
<td>LNG</td>
<td>Moto Services, Popular 2000 Ltd</td>
</tr>
<tr>
<td>8</td>
<td>Tebay</td>
<td>LNG</td>
<td>M6 Diesel Services</td>
</tr>
<tr>
<td>9</td>
<td>Shareshill</td>
<td>LNG</td>
<td>M6 Diesel Ltd, Saredon Filling Station</td>
</tr>
<tr>
<td>10</td>
<td>Northamptonshire</td>
<td>LNG</td>
<td>DIRFT</td>
</tr>
</tbody>
</table>

9.2.3  The Netherlands

The Netherlands has over 8 operating LNG fuelling stations and more than 100 LNG-fuelled trucks on the road. The “Nationaal LNG plateform” highlights the high potential of LNG in the Netherlands and ensures that by 2015, 500 trucks will be fuelled with LNG.

Public and private refilling stations are stated below:

<table>
<thead>
<tr>
<th>No.</th>
<th>Refuelling Station</th>
<th>Natural Gas Fuel</th>
<th>Owner and Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oss, N. Brabant</td>
<td>LNG</td>
<td>Vos Logistics</td>
</tr>
<tr>
<td>2</td>
<td>Oss, N. Brabant</td>
<td>LNG &amp; L-CNG</td>
<td>Rolande LNG B.V.</td>
</tr>
<tr>
<td>3</td>
<td>Tilburg, N. Brabant</td>
<td>LNG &amp; L-CNG</td>
<td>Rolande LNG B.V.</td>
</tr>
<tr>
<td>4</td>
<td>Amsterdam, N. Holland</td>
<td>LNG</td>
<td>Simon Loos</td>
</tr>
<tr>
<td>5</td>
<td>Zwolle, Overijssel</td>
<td>LNG &amp; L-CNG</td>
<td>Salland Ollie/LNG 24</td>
</tr>
<tr>
<td>6</td>
<td>Delfgauw</td>
<td>LNG</td>
<td>Albert Heijn</td>
</tr>
<tr>
<td>7</td>
<td>Utrecht, Utrecht</td>
<td>LNG</td>
<td>Rolande LNG B.V.</td>
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<tr>
<td>8</td>
<td>Duiven</td>
<td>LNG</td>
<td>LNG Solutions GDF SUEZ</td>
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</tbody>
</table>
9.2.4 Sweden

Sweden features over 5 refuelling stations.

Public and private refuelling stations are stated below:

<table>
<thead>
<tr>
<th>No.</th>
<th>Refuelling Station</th>
<th>Natural Gas Fuel</th>
<th>Owner and Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Göteborg, Stig Center</td>
<td>LNG &amp; L-CNG</td>
<td>Fordonsgas</td>
</tr>
<tr>
<td>2</td>
<td>Järna, Södertajle</td>
<td>LNG &amp; L-CNG</td>
<td>Statoil/AGA</td>
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<tr>
<td>3</td>
<td>Malmö</td>
<td>LNG</td>
<td>Preem/EON</td>
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<td>Älvsjö</td>
<td>LNG</td>
<td>AGA Gas AB</td>
</tr>
<tr>
<td>5</td>
<td>Jönköping, Finnvedens Lastvagnar</td>
<td>LNG &amp; L-CNG</td>
<td>Fordonsgas</td>
</tr>
</tbody>
</table>

9.2.5 Portugal

GoldEnergy has built a gas complex including LNG/L-CNG refuelling station in Mirandela, Tras os Montes.
10 Conclusion

The LNG production plants and terminals have a set of requirements defined for production and storage of the fuel. However, the storage at small LNG stations and the regulations for building LNG service stations are not always covered in legal texts and requirements. In common with most industries, LNG transportation is subject to a myriad of international, regional, and national standards and procedures.

Currently, due to the fact that LNG technology for vehicles is still taking off in Europe, there is a lack of technical legislation on the subject. However, standardisation bodies such as UNECE and ISO are currently working on solving standardisation issues.

In Europe, the codes and regulations specific to LNG import facilities include:

- **European Union Seveso II Council Directive** 96/82/EC of 9 December 1996 - Control of Major-Accident Hazards involving Dangerous Substances. For the European Union all operation and maintenance activities are under the control of a Safety Management System required by Directive Seveso II 96/82/EC.
- **EN 1473** - “Installation and equipment for LNG – Design of onshore installations”
- **EN 1160** - “Installation and equipment for Liquefied Natural Gas – General characteristics of liquefied natural gas”

The following US standards may also be applied in Europe:

- **NFPA 52** - for safety in CNG and LNG fuel systems and fuelling facilities;
- **NFPA 59A** - Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG); and

Applying their own regulations derived from the Seveso II Directive, national authorities of each European country have the responsibility to issue a certificate to the facility and are the lead agency for review of environmental and safety concerns, including public comment meetings and review procedures.

There are very few countries with an integral regulation on the building and operation of LNG stations. It is common that such regulation will develop when a country has one or more stations in operation.
11 Recommendations

The LNG operations should be conducted by properly trained personnel according to pre-established formal procedures to prevent accidental releases and fire/explosion hazards. Procedures should include all aspects related to the LNG as fuel for transport of large distance.

Uncontrolled releases of LNG could lead to jet or pool fires if an ignition source is present, or a methane vapour cloud which is potentially flammable (flash fire) under unconfined or confined conditions if an ignition source is present.

LNG spilled directly onto a warm surface could result in a sudden phase change known as a Rapid Phase Transition (RPT).

Recommended measures to prevent and respond to LNG spills include the following:

- Conduct a spill risk assessment for the facilities and related transport activities.
- Develop a formal spill prevention and control plan that addresses significant scenarios and magnitude of releases. The plan should be supported by the necessary resources and training. Spill response equipment should be conveniently available to address all types of spills, including small spills.
- Spill control response plans should be developed in coordination with the relevant local regulatory agencies.
- Facilities should be equipped with a system for the early detection of gas release and to help pinpoint its source so that operator initiated ESD can be rapidly activated, thereby minimizing the inventory of gas releases.
- An Emergency Shutdown and Detection (ESD/D) system should be available to initiate automatic transfer shutdown actions in case of a significant LNG leak.

Recommendations LNG facilities

LNG facilities should be designed, constructed, and operated according to international standards for the prevention and control of fire and explosion hazards, including provisions for safe distances between tanks in the facility and between the facility and adjacent buildings.

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

Implementing safety procedures for loading and unloading product to transport systems, including use of fail-safe control valves and emergency shutdown and detection equipment (ESD/D) should be performed.

Also, it is necessary the preparation of a formal fire response plan supported by the necessary resources and training, including training in the use fire suppression equipment and evacuation. Procedures may include coordination activities with local authorities or neighboring facilities. Prevention of potential ignition sources such as:

---

ESD: Emergency Shutdown and Detection
• Proper grounding to avoid static electricity build up and lightning hazards (including formal procedures for the use and maintenance of grounding connections);
• Use of intrinsically safe electrical installations and non-sparking tools;
• Implementation of permit systems and formal procedures for conducting any hot work during maintenance activities, including proper tank cleaning and venting,
• Application of hazardous area zoning for electrical equipment in design; Facilities should be properly equipped with fire detection and suppression equipment that meets internationally recognized technical specifications for the type and amount of flammable and combustible materials stored at the facility. Examples of fire suppression equipment may include mobile / portable equipment such as fire extinguishers, and specialized vehicles. Fixed fire suppression may include the use of foam towers and large flow pumps. The installation of halon-based fire systems is not considered good industry practice and should be avoided. Fixed systems may also include foam extinguishers attached to tanks, and automatic or manually operated fire protection systems at loading / unloading areas. Water is not suitable for fighting LNG fires as it increases the vaporization rate of LNG, but.

All fire systems should be located in a safe area of the facility, protected from the fire by distance or by fire walls; Explosive atmospheres in confined spaces should be avoided by making spaces inert;

Provision of fire safety training and response as part of workforce health and safety induction / training, including training in the use fire suppression equipment and evacuation, with advanced fire safety training provided to a designated fire fighting team.

**Contact with Cold Surfaces**

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

**Confined Spaces**

Confined space hazards, as in any other industry sector, are potentially fatal to workers. Confined space entry by workers and the potential for accidents may vary among LNG facilities depending on design, on-site equipment, and infrastructure. Confined spaces may include storage tanks and secondary containment areas. Facilities should develop and implement confined space entry procedures.

**Health and Safety**

Health and safety impacts during the construction and decommissioning of facilities are common to those of most other industrial facilities.

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

LNG facilities should prepare an emergency preparedness and response plan that considers the role of communities and community infrastructure in the event of an LNG leak or explosion.

Regulation

Currently, due to the fact that LNG technology for vehicles is still taking off in Europe, there is a lack of technical legislation on the subject. However, standardisation bodies such as UNECE and ISO are currently working on solving standardisation issues.

There are very few countries with an integral regulation on the building and operation of LNG stations. It is common that such regulation will develop when a country has one or more stations in operation. It can also be expected that the ISO regulation on LNG stations will become a guideline for these regulations.
List of Tables

Table 2-1 Summary of the safety and environmental implications of LNG properties ........................................12
Table 7-1 Safety analysis and comparison with other fuels – Vehicle transportation ............................................46
Table 7-2 Safety analysis and comparison with other fuels – Fuel storage ..........................................................49
Table 7-3 Safety analysis and comparison with other fuels – Vehicle fuel storage tank .....................................51
Table 9-1 Public and private refilling stations in Spain ..........................................................................................57
Table 9-2 10 public and private refilling stations in UK .....................................................................................58
Table 9-3 Public and private refilling stations in Netherlands .................................................................................58
Table 9-4 Public and private refilling stations in Sweden .......................................................................................59

List of figures

Figure 1-1. Impression of the LNG Blue Corridors .................................................................................................7
Figure 1-2 Regulatory framework .........................................................................................................................9
Figure 2-1 LNG flammability range .......................................................................................................................12
Figure 3-1 Basic components of an LNG fuelling station .....................................................................................15
Figure 4-1 The Hazard – Related assessment process .........................................................................................17
Figure 4-2 HAZOP procedure illustration ........................................................................................................21
Figure 5-1 Typical safety features present at an LNG fuelling station .................................................................32
Figure 5-2 Drivers undergo LNG refuelling training in Tiburg NL .................................................................36
Figure 5-3 Video training setup in Commerce CA, USA ..................................................................................36
Figure 5-4. Hose connection in the vehicle ........................................................................................................39
Figure 5-5. Hose disconnection in the vehicle ...................................................................................................40
Partners

<table>
<thead>
<tr>
<th>Applus+ IDIADA</th>
<th>Ballast Nedam</th>
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