CNSS
Clean North Sea Shipping

CNSS Work package 4, Showcase LNG

LNG fuelled ships as a contribution to clean air in harbours

CNSS

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Photo: Deen Shipping

1 Introduction

1.1 Clean North Sea Shipping

The Clean North Sea Shipping (CNSS) project, involving 18 partners from six countries, seeks to address the problems caused by air pollution and greenhouse gases produced by ships operating along the North Sea coast and within North Sea ports and harbours. A reduction in exhaust gas emissions from ships will improve the general environmental situation in the North Sea Region.
The CNSS project aims to create awareness, share knowledge and convince influential stakeholders, including regional and European politicians, ports, shipping companies and cargo owners, to take action.

1.2 LNG showcase

This report is the result of one of the activities of the WP4 Clean Shipping Technology work package called the LNG (Liquefied Natural Gas) showcase. The main purpose of the showcase is to increase awareness and understanding among policy makers and other stakeholders of gas-fuelled ships as a potential Clean Shipping Technology.
The showcase report will provide an introduction to LNG or biogas as an alternative fuel for ships and answer most of the questions that the stakeholders might have relating to this technology.

1.3 Main contributors

The main contributors to this report are as follows:

Chapter	Main contributor
1	White Smoke Consulting on behalf of Hordaland County Council
2	White Smoke Consulting on behalf of Hordaland County Council
3	Swedish Marine Technology Forum
4	Swedish Marine Technology Forum
5	Port of Antwerp
6	Germanischer Lloyd
7	Germanischer Lloyd
8	BSU Hamburg together with Helmholtz-Zentrum Geesthacht
9	White Smoke Consulting on behalf of Hordaland County Council
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11	White Smoke Consulting on behalf of Hordaland County Council
12	GASNOR
13	White Smoke Consulting on behalf of Hordaland County Council

Groningen Seaports and the Port of Harlingen are acknowledged for their contribution at different stages of the report compilation. The Port of Gothenburg and Maritime Kompetenzzentrum in Leer (MARIKO) are also acknowledged for their contribution and participation in the early stages of the WP4 work package of the CNSS project.

1.4 Report structure

The report is structured as follows:

- Chapter 1 and 2 provide an introduction to, and a summary of, the main issues.
- Chapters 3 to 11 highlight specific aspects of the introduction of LNG as marine fuel and provide an overview of each topic. For those interested in finding out more about some of the topics discussed, references to further sources of information are provided throughout the report. For chapter 5 and 7, supplementary information is available in the appendices.
- Chapter 12 illustrates many of the topics discussed in the preceding chapters with a specific reference case—the Gasnor LNG bunkering facility establishment in the port of Brunsbüttel, close to the North Sea entrance of the Kiel Canal and the main entrance to the Port of Hamburg.
- Chapter 13 concludes the report with recommendation for different stakeholders provided by the participants in the LNG showcase work.

1.5 Limitations

The purpose of this showcase report is to provide an insight into most, if not all, of the topics to be addressed when considering LNG bunkering and to provide additional references for further information. This report will not contain detailed information, nor will it provide complete guidelines on establishing and operating LNG bunkering.

1.6 Abbreviations and definitions

AND	International Carriage of Dangerous Goods by Inland Waterways
ADR	International Carriage of Dangerous Goods by Road
AIS	Automatic Identification System
API	American Petroleum Institute
BLG	International Maritime Organisation (IMO) sub-committee dealing with Bulk Liquids and Gases
BOE	Barrel of oil equivalent
CCNR	Central Commission for the Navigation of the Rhine
CEN	European Committee for Standardization
CFR	Code of Federal Regulations
CNG	Compressed natural gas
CH_4	Methane
CO_2	Carbon dioxide
DMA	Danish Maritime Authority
ECA	Emission Control Area
EGR	Exhaust gas recirculation
EIA	Environmental Impact Assessment
EMSA	European Maritime Safety Agency
ESD	Emergency Shut Down
ESPO	European Sea Ports Organization
EU	European Union
Flemish	
Study	Solutions for the provision of LNG as shipping fuel in Flemish ports
Fracking	A method to extract shale natural gas (NG) from flaky shale rock
FOB	Free On Board (as defined in the Incoterms 2010 by the International Chamber of Commerce)
GHG	Greenhouse Gas. Emissions of gaseous substances that trap heat in the atmosphere and contribute to the Green House effect and climate change.
GJ	Giga Joule
GL	Germanischer Lloyd
HA	Hazardous Area. An area in which an explosive gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of apparatus. [ISO 18132-2:2008, 3.3]
HAZID	Hazard Identification
HFO	Heavy Fuel Oil
IAPH	International Association of Ports and Harbours
IEA	International Energy Agency
IGC	International Code For The Construction And Equipment Of Ships Carrying Liquefied Gases In Bulk
IGF Code	International Code of Safety for Ships Using Gases or other Low Flashpoint Fuels (draft)
IGF vessel	A vessel using LNG as main fuel designed and operated for international trade in line with the IMO regulations
IGO	Intergovernmental organization
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organisation
ISGINTT	International Safety Guide for Inland Navigation Tank-barges and Terminals
ISGOTT	International Safety Guide for Oil Tankers and Terminals
ISO	International Organization for Standardization

IWS	Inland waterway shipping
Liquefied gas tankers	A tanker that transport liquefied gases such as LNG, LPG, Ethylene, Carbon Dioxide and so on.
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MGO	Marine Gas Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MGO	Marine Gas Oil
MOW	Mobiliteit en Openbare Werken (Flemish Department of Mobility and Public Work)
NaOH	Sodium hydroxide (also known as lye or caustic soda)
Natural gas	A hydrocarbon gas mixture consisting mainly of methane. The composition of the gas may also include varying amounts of nitrogen, carbon dioxide and so on.
NFPA	National Fire Protection Association
NG	Natural gas
NGO	Non-governmental organization
NO_x	Nitrogen oxides
OCIMF	Oil Companies International Marine Forum
PM	Particulate matter
PSV	Platform supply vessel
QCDC	Quick Connect Disconnect
RPT	Rapid phase transition
RVIR	Rhine Vessel Inspection Regulations
SAR	Search and rescue
SCR	Selective Catalytic Reduction
SECA	Sulphur Emission Control Area
SIGTTO	Society of International Gas Tanker & Terminal Operators
SO_2	Sulphur dioxide
SOLAS	International Convention for the Safety of Life at Sea
SO_x	Sulphur oxides
STCW	International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers
STW	IMO sub-committee dealing with Standards of Training and Watchkeeping
UN	United Nations
UNECE	United Nations Economic Commission for Europe
WPCI	World Port Climate Initiative

2 Summary

Since the beginning of the 21st century, there has been increasing global interest in switching to LNG as an alternative marine fuel. This trend began with the delivery of MF Glutra in 2000, which became the first vessel, other than LNG carriers, to use LNG as marine fuel. MF Glutra was the result of a joint development project between the Norwegian authorities, Det Norske Veritas (DNV) and the ferry operator MRF.

Since the launch of MF Glutra, Norway has been heavily involved in the development in LNG technology and today (spring 2013) there are approximately 40 Norwegian vessels that use LNG as their main fuel. This includes vessels under construction.

Interest outside Norway in using LNG as marine fuel is generally attributed to the revised MARPOL Annex VI regulations and the introduction of the North European Emission Control Area (ECA) in 2008. This promoted interest in LNG for international shipping, and in particular for short sea shipping in Europe. Global interest in using LNG as marine fuel for all types of shipping, involved in all kinds of trades, continues to grow as many believe LNG as may be able to supply all kinds of shipping with a much more environmentally friendly fuel at a similar, or even reduced, cost compared to the present fuel used by shipping.

However, there are still some challenges to overcome before LNG will be widely adopted within shipping communities. As LNG has to be maintained at approximately -160 ° C to be kept liquid at atmospheric pressure, the handling of LNG is more complicated compared to traditional fuel oils. This places new demands on the distribution and handling infrastructure as well as on ship design, knowledge, training, safety precautions and so on. To meet these demands, significant investment is required in infrastructure, training and education.

In addition, traditionally LNG hasn't been traded in small quantities based on short-term contracts. This means a new set of business models and commercial arrangements will be required before the LNG marine fuel market can compete with the existing marine fuel oil market. As these changes all require significant investment, the transition to LNG as the preferred marine fuel has so far been slow except in Norway where the development of LNG has been heavily promoted by the national and regional governments.

From a societal perspective, and perhaps the primary motivation to support the adoption of a new marine fuel, switching from traditional fuel oils to LNG would result in significant health and environmental improvements without a significant increase in the cost of transportation.

Photo: Petter Husby

Figure 1: The LNG ferry MF Fannefjord crossing a Norwegian fjord

3 LNG supply chain

3.1 Introduction

This chapter describes a suggested supply chain for LNG as marine fuel. This supply chain is illustrated in the following diagram and the subsequent sections describe each part of the supply chain.

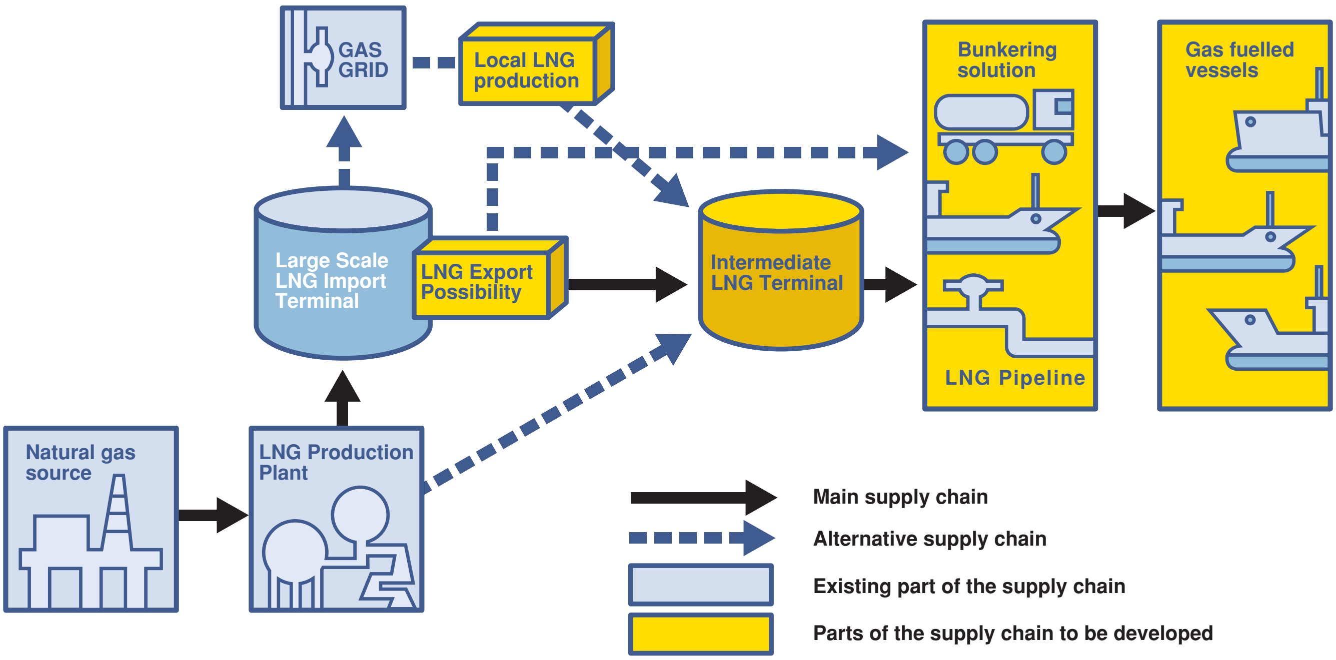


Figure 2: The LNG supply chain (to be changed)

3.1.1 Main supply chain

The main supply chain illustrated in Figure 3 is probably the most likely solution for supplying LNG to vessels within the North Sea area, at least in the longer term when demand and volumes are expected to be sufficiently high enough to cover the costs of each step in the distribution process.

Figure 3: The main supply chain

It is important to understand that every additional step in the supply chain could adversely affect the quality of the LNG as the temperature of the liquid may rise each time pumping from one part of the supply chain to another is required. The choice of distribution will of course differ from case to case based on specific commercial and technical conditions such as the frequency of customer visits and the size of terminal. Some of the main alternative supply models are discussed in the following sections.

3.1.2 Alternative supply chains

The following supply chains may also be appropriate for the North Sea area.

Figure 4: Alternative supply chain No 1

The supply chain illustrated in Figure 4 is likely to be adopted for smaller vessels that have an LNG bunker batch demand up to 100 m^3 and want to bunker within a reasonable distance from an LNG import terminal with sufficient truck export facilities. Supply by truck will probably also be considered for larger vessels as an intermediate solution in the early stages of LNG infrastructure development.

Figure 5: Alternative supply chain No 2

The supply chain described in Figure 5 is likely to be adopted for smaller vessels with an LNG bunker batch demand < 50 m^3 and a preferred bunkering position either at a remote location relative to a large-scale LNG import terminal, or in the vicinity of a large-scale LNG import terminal where the truck export facilities are not sufficient.

Figure 6: Alternative supply chain No 3

The supply chain described in Figure 6 is likely to be adopted for vessels that have an LNG bunker batch demand >100 m^3 and want to bunker within a reasonable distance from a large-scale LNG import terminal with sufficient vessel export facilities.

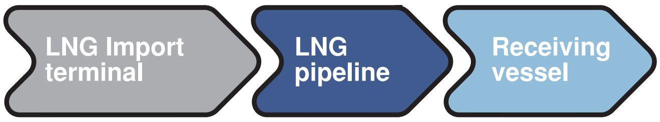


Figure 7: Alternative supply chain No 4

The supply chain described in Figure 7 is likely to be adopted for vessels that have the ability to visit an LNG import terminal or LNG production plant with dedicated LNG bunkering facilities. At present, this option will only be available at a few locations. Most large-scale terminals would probably not have this type of direct export facility for receiving vessels.

In addition to the supply chain alternatives describe here, the following technologies could also become potential supply solutions for gas-fuelled vessels in certain situations:

- LNG by local liquefaction from NG-pipeline
- Container/trailer tank distribution—For example RoRo (Roll-on, Roll-off) vessels
- Compressed natural gas (CNG)—For example smaller vessels such as commuter ferries

3.2 LNG Source

From a North Sea perspective, the LNG source is defined as either existing and planned LNG receiving terminals or small-scale LNG production plants available within the North Sea area.
Receiving terminals import LNG but store and redistribute the fuel as a gas, primarily to gas grids via pipelines. To use LNG as a fuel for shipping, LNG must be redistributed in its liquid state. This means there is a requirement to establish loading facilities and export terminals for both trucks and ships. LNG truck loading facilities will have to be designed and built to transport LNG via trucks to end users.

Figure 8: Map of LNG terminals

LNG vessel loading and export terminals will also be required. It is vital that the new export facilities do not interfere with the operations of the import terminal, and that both import and export terminals can operate independently.

The size of ships that will load LNG at an export terminal may vary. There will probably be both LNG Bunker and Feeder vessels loading at the export facility. Ideally other types of LNG fuelled vessels could also be using the facilities to bunker LNG. The design of export terminals for both trucks and vessels should also take possible future expansion into consideration.

3.3 Intermediate terminal

An intermediate, or redistribution, LNG terminal may be used if the distance from an LNG source to an end user is longer than that considered practical for a bunker vessel or truck to cover. Another example of an intermediate terminal is a small LNG tank used for local bunkering through pipelines to smaller consumers such as harbour tug, fishing vessels or small ferries.

As described in the distribution system schematic in Section 3.1, an intermediate LNG terminal may be supplied with LNG by:

- LNG bunker ship
- LNG feeder ship
- LNG truck

The choice of supply method generally depends on the use and size of the terminal.
The distribution system schematic in section 3.1 also shows that an intermediate LNG terminal may export to end users via:

- LNG bunker ship
- LNG feeder ship (usually for large-scale bunkering situations where the LNG feeder ship acts as a bunker ship)
- LNG truck
- Pipeline

Again, the export method will depend on the use and size of the terminal.

An intermediate LNG terminal may vary in size depending on the purpose of the terminal. In a full-scale application an LNG terminal in a large port, as distinct from the import terminals, could be as large as 100,000 m^3. By comparison, an intermediate LNG terminal serving small fishing vessels or tugboats through a pipeline at a bunkering quay may have a capacity of less than 100 m^3.
It should also be noted that the bunker terminal might

Photo: AGA AB

Figure 9: Intermediate LNG terminal at Nynäshamn, Sweden

be a barge or ship serving as an intermediate terminal. In this case, a bunker vessel as well as an LNG-fuelled ship will be able to moor alongside and bunker LNG.

3.4 Bunker vessel

An LNG bunker vessel will be a smaller and more manoeuvrable vessel compared to an LNG feeder vessel. As with LNG feeder vessels, LNG bunker vessels will probably vary in size and dimension depending on the actual conditions. Today, there are designs for LNG bunker vessels between 500 and 6,000 cubic meters in size. To serve a wider range of vessels, LNG bunker vessels could be designed to carry both LNG and other fuel oils. To be as environmental friendly as possible, the LNG bunker vessel itself should have an LNG main engine installed and be propelled by LNG. High capacity cargo pumps and an efficient distribution system should ensure fast and safe bunker operations.

Photo: FKAB Marin Design and White Smoke AB

Figure 10: Typical LNG Bunker vessel designs

3.5 Feeder vessel

The main purpose of the feeder vessel is regional distribution of LNG bunker fuel. The LNG would be discharged from larger import terminals to receivers along the coast line. The primary receivers would be intermediate LNG storage tanks of varying size, or bigger vessels in need of large quantities of LNG as bunker fuel. The size and dimensions of an LNG feeder vessel will vary considerably, depending on different market demands, vessel manoeuvrability, water depths and other physical limitations at the ports and bunker sites to be used. The typical cargo capacity for LNG feeder vessels is expected to be in the range of 7,000 - 20,000 m^3 approximately. The onboard equipment would be chosen to make the feeder vessels as flexible as possible given LNG cargo considerations. This would include several LNG cargo tanks, submerged deep-well cargo pumps and a dual fuel main engine. The main fuel of the LNG feeder vessel could be boil-off gases and regasified LNG from the cargo tanks but the main engine could be of dual fuel type to increase the redundancy of the vessel.

As LNG feeder vessels will be delivering LNG bunker fuel to LNG intermediate tanks as well as to other vessels, good manoeuvrability is essential for feeder vessels and they should be equipped with bow thrusters, high performance rudders

Photo: Gasnor

Figure 11: Gasnor LNG truck


Photo: Gasnor

Figure 12: Gasnor LNG pipeline

and so on. LNG feeder vessels should be easy to operate during coastal navigation and mooring operations to minimise the use of harbour tugs to perform bunker operations.

3.6 LNG Truck

A specially adapted truck is a widely used transport option when it comes to LNG. The truck can carry between 40 to 80 m^3 of LNG depending on the permitted operating size of trucks in specific countries. An LNG truck is filled and emptied the same manner as a normal IMO type C tank. There are two main options to transfer LNG from the truck to the receiver—either by increasing the pressure in the tank of the truck or by pumping the LNG. The first option, to increase the pressure in the truck's LNG tank, is slower but requires less equipment on the truck. Pumping the LNG may result in higher transfer rates, although a typical hose size for LNG trucks is only two - three inches. A normal bunkering operation from a semi-trailer like the one illustrated in Figure 11, may take up to two hours, including the signing of documents and complying with all safety procedures. The actual fuel transfer time approximately one hour. Transporting LNG by truck tends to be less cost effective than ship transportation if the volumes of LNG involved are sufficiently large over a sustained period of time. The optimal transport distance for LNG trucks is up to 600 km approximately.

3.7 LNG Pipeline

It is technically challenging and expensive to transport LNG over long distances via a pipeline. As a result, it is anticipated that the use of pipelines for LNG distribution will be restricted to the short distances between from LNG tanks to fixed bunkering stations. Boil-off gas in the pipeline must also be taken into consideration, especially when the pipeline is not used.

3.8 Receiving vessels

At present, the receiving vessel will most likely be using a pressurized IMO type C tank, depending on the size of the vessel. The pressurized tank will be able to accommodate the increased pressure that arises during bunkering operations.

From safety perspective, LNG is very different to normal fuel oils in many respects. During bunkering operations, two properties of LNG are particularly important:

- LNG is a very cold (cryogenic) liquid
- LNG in gaseous form has a very low flash point

These two properties mean additional requirements for handling, storage, ventilation and ancillary equipment on both the receiving vessel as well as the supply systems. The requirement to ensure the bunkering area on the receiving vessel is an all EX-classified and restricted area during bunkering operations is still under discussion. Inside the HA, all electrical equipment is subject to additional safety requirements and electric energy should be low to avoid ignition of LNG vapour. The extent of the HA and restricted area is also still under debate and remains to be clarified. It is not yet clear if it will be possible to use a general HA or if the restricted zone has to be adapted for each specific bunkering occasion.

A bunkering station should be located on each side of the receiving vessel, preferably on a lower deck and along the flat section, especially if ship to ship bunkering is to be considered. Although bunkering options on both sides of the vessel may be a more expensive to install, this is the normal configuration of vessels bunkering fuel oils today. The location of the bunker stations should facilitate hose handling and communication for the bunker operator, and ensure the safety of the bunkering operators on both the receiving ship as well as on the supplying source.

Each manifold in the bunker station should be equipped with Break-Away couplings to ensure maximum safety and minimal leakage. Different drip trays should also be located under the manifolds, optimized for the kind of liquids that will be transferred. For LNG manifolds, the drip tray must feed directly out to sea, to ensure all leakage is drained overboard. For fuel oil and other liquids, any leakage should be halted and kept onboard.

The location and design of the bunkering stations should also take into consideration the natural ventilation requirements for bunkering operations.

4 LNG stakeholders demands

4.1 Introduction

The following section describes the demands on LNG stakeholders from two perspectives. First, the action required by each stakeholder to ensure a small-scale LNG for shipping infrastructure becomes a reality. Secondly, to meet these requirements, stakeholders themselves demand that certain criteria must be met for the stakeholder to invest in, or support, the implementation of LNG for shipping technology. Some of these demands are critical to the development of an LNG infrastructure, while other demands are not considered critical, but are still important requirements.

Figure 13: Illustration of LNG stakeholder demands (figure to be completed by SMTF/Hordaland)

4.2 Ship owners/operators

Ship owners have an essential role to play in creating the new infrastructure for LNG as marine fuel. Without a demand from ship owners to use LNG as fuel, no new infrastructure will be possible. The LNG infrastructure requires a sufficient amount of investment in new LNG-fuelled ships or the conversion of existing shipping to use LNG marine fuel. The first adopters must be prepared to assume the risk of possibly choosing the wrong technology due to the current uncertainty of future costs of using LNG compared to fuel oils and other alternatives.

Before ship owners will invest in LNG-fuelled vessels, they are likely to demand the following conditions:

- The price of LNG as marine fuel must be competitive compared to HFO and cleaning solutions.
- The availability of LNG must be reliable. LNG bunkering infrastructure must be available in most, if not all, ports used by the ship owner (assured availability).
- The regulatory framework should be clear regarding design, operations and emissions.
- Tried and tested bunkering procedures must be in place. The question of whether LNG bunkering can be undertaken simultaneously with cargo handling must be answered—bunkering must not cause delays or result in longer stays in port.

4.3 Policy makers

Policy makers such as legislators and governments at local, regional, national and EU level need to show clear support for clean shipping technologies, including LNG. Without the support from politicians at all levels, it will be difficult to set up the necessary infrastructure. The policies promoting alternative fuels must be long-term in vision, and the supporting legislation should be harmonized and implemented fairly and consistently across countries and different types of technology. In the early stages of implementation, some form of public financial funding or incentive schemes will be probably be required to support the initial investments in LNG vessels and

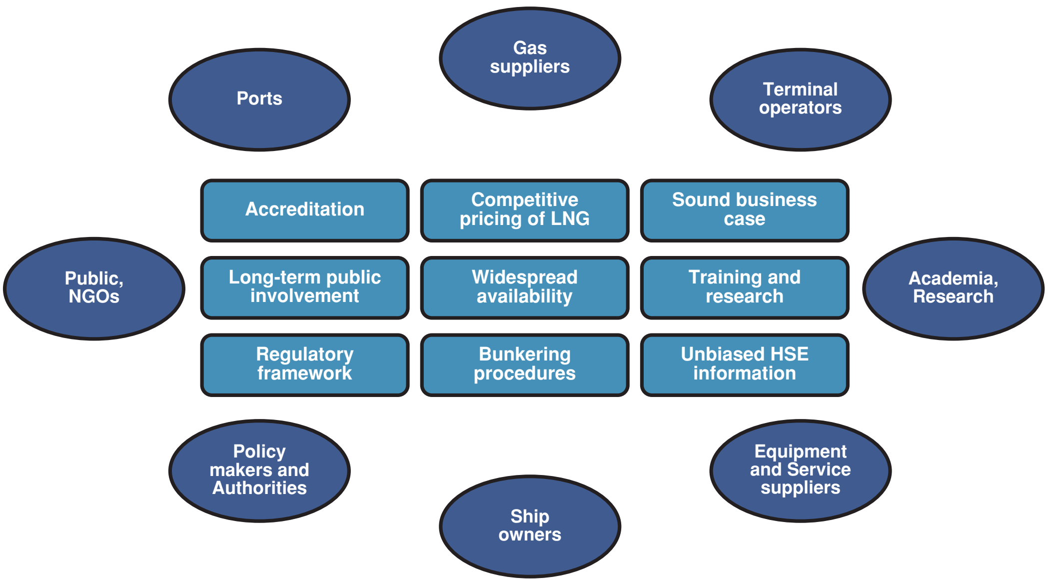


Figure 12: LNG stakeholders and important demands.

bunkering infrastructure as well as the work required to establish the necessary regulatory framework.

On the other hand, for policy makers to take a standpoint and make important decisions that will be required, they will need credible and unbiased information on LNG as a potential clean marine fuel, addressing both the risks and benefits regarding health, safety and environment. Any input to the process must be of high quality to support policy making decisions. The political decision makers must have a realistic view of the technical and financial challenges posed by LNG and possible implications for the other stakeholders.

4.4 Authorities

Authorities such as transport, safety, environment and similar bodies are of crucial importance for implementing the LNG for shipping infrastructure. The support of these authorities will be essential for implementing and enforcing the necessary regulatory framework. The regulations should be set at an appropriate level to ensure safety, but be flexible enough to accommodate shipping business operations. The authorities must communicate their requirements to other stakeholders and acquire sufficient knowledge of the LNG infrastructure through either their own or third party studies. These authorities may be required by politicians to provide many of the expert statements that will inform the decision making process.

The authorities will require clear directives and financial support from the policy makers to complete the research and detailed investigation into what will be required to set up the appropriate regulatory framework. Authorities will also require detailed information from various stakeholders, research organisations, and so on to support their decisions.

4.5 Ports

The ports are a crucial part of the LNG supply chain. From a sustainable LNG infrastructure perspective, a sufficient number of ports must make locations available for small-scale LNG terminals and bunker facilities. The port authority needs to establish local regulations and port by-laws, approved by other relevant authorities. In addition, the ports may be a possible source of funding for investment support. For example, the Port of Antwerp is planning to develop an LNG bunker vessel to support the growing interest in using LNG as marine fuel. Another example is the Port of Gothenburg, which has decided to invest three billion SEK in the necessary logistics to offer ships the possibility to bunker LNG (Henriksson, 2012).

The following points describe some of the general requirements that should be met before port authorities will support the establishment of an LNG infrastructure.

- Available space both onshore and offshore
- A sound business case for the port with sufficient LNG fuel demand from the users
- Support from the owner(s) of the port
- Possible internal or external funding
- An established regulatory framework
- Accreditation of bunker companies

4.6 Terminal operators

The terminal operators are independent companies building and operating the LNG terminal on the port premises, where the LNG will be stored and distributed to different customers. If this step is not managed by the port or the gas supplier, the LNG infrastructure demands the support of a competent terminal operator who can establish and run the terminal and also offer a realistic contract model for gas suppliers regarding quantities and contract length (short-term versus long-term).

Terminal operators will require sufficient user demand with the potential economies of scale offered by different types of gas users such as the energy sector, manufacturing industries, shipping, and land transportation (car, trucks, and so on.). Moreover, the regulatory framework should be in place, and external funding may also be necessary to persuade potential operators to commit to investing in a new terminal.

4.7 LNG suppliers

Gas as fuel for ships is a potentially new market for gas suppliers, although by comparison to the total gas consumption market, the LNG marine fuel market will be relatively small.

If LNG as marine fuel is going to be an attractive alternative for shipping, the gas suppliers must be able to offer stable gas deliveries and competitive prices compared to other options for fuel and cleaning technologies. Contracts with ship and terminal operators should be reasonable in terms of price, quantities and length of contract. It is also important that gas suppliers, together with terminal operators, define and adhere to a minimum quality range of LNG.

If a gas supplier is going to deliver LNG to ships, there must be sufficient user demand. The shipping industry will probably take a relatively small share of the total gas deliveries, but with the right location of terminals there are bunkering opportunities for a large number of ships of different categories and the possible economies of scale advantages from other types of users. The small-scale LNG supply chain is still under development, as is the regulatory framework for using LNG as marine fuel. When the supply chain and regulatory framework are established, shipping is likely to be a growing market for many gas suppliers.

4.8 Others

4.8.1 Equipment and service suppliers

The various marine technology suppliers are important players in the development of a successful infrastructure for LNG as marine fuel. Engine manufacturers and other equipment and service suppliers must have the appropriate technology available and the capacity to deliver the necessary equipment to meet the demand. Most of the technology solutions regarding using LNG as fuel are available today, but further improvements are still required. The technology suppliers will continue to develop their equipment if they can expect enough potential demand from ship owners who are ready to upgrade their fleet.

Photo: Liquiline

Figur 14: Liquiline semitrailer discharging to ferry

4.8.2 Research and education

As with many new technologies, there is also a need for research and training. Independent studies by research institutions and similar organisations are important to establish a scientific basis for the real cost and benefits of using LNG as marine fuel by comparison to the alternatives. Universities and other educational organisations are also important in developing the necessary training courses and educational programs for onboard and offshore crew, authorities and related organisations as to the correct procedures for using LNG as fuel for ships.
For these institutions to consider this matter a priority, it may be necessary to issue policy directives and offer financial support to set up research and educational programs. Chapter 11 will provide further information on LNG education and training.

4.8.3 General public

The general public may not be regarded as a direct stakeholder in the development of the LNG for shipping infrastructure, but their indirect support and acceptance of using this technology is still important. People require safe and environmentally friendly transport at a reasonable price. It may be necessary for the other stakeholders to inform and educate the general public about using gas and LNG for shipping. In particular, it seems that safety issues should be addressed and explained, but also the possible environment and health benefits that comes with a cleaner fuel alternative. In the end, it is often the wishes of the general public that direct future policies.

4.8.4 Non-governmental organisations

As with the general public, non-governmental organisations such as environmental groups might not be considered as direct stakeholders in developing LNG for shipping infrastructure. However, their indirect, and occasionally direct, support and acceptance of this technology may prove to be very important. The NGOs will be in favour of safe, clean and environmentally friendly transport.

5 Existing and future regulations, standards and legislations

This chapter gives a brief overview of the present regulations, standards and legislation regarding LNG. The initiatives that are currently being undertaken by governmental and private bodies are also discussed. Further information can be found in the Flemish Study.

5.1 Regulations for marine activities

The regulatory framework for seagoing vessels is overseen by the International Maritime Organization (IMO). A brief overview of the most relevant parts of the framework is provided in the following sections.

5.1.1 Emission Control Area

Stricter emission controls than those required at a global level are enforced in specifically designated geographical areas. An Emission Control Area (ECA) can be designated for SO_X, NO_X or both. An ECA (NO_X and SO_X) comes in effect in 2012 in North America, which includes most of the US and Canadian coasts. The Baltic Sea, the North Sea and the English Channel have been designated as an ECA for SO_X emission reduction, also referred to as a Sulphur Emission Control Area (SECA). This restriction means that the maximum allowable sulphur content of bunker fuel is 1% (from July 1, 2010) and 0,1% from January 1, 2015 (MOW, 2012).

5.1.2 SOLAS

The International Convention for the Safety of Life at Sea (SOLAS) is an international maritime safety treaty. SOLAS requires member states to ensure that their ships comply with minimum safety standards with respect to construction, equipment and operation. Chapter VII of this treaty requires the carriage of all dangerous goods to be in compliance with the International Maritime Dangerous Goods Code (IMDG) but it contains no specific reference to the use of LNG. The construction and equipment of ships carrying liquefied gasses in bulk and gas carriers is determined in SOLAS to comply with the International Gas Carrier Code (IGC code) (MOW, 2012).

5.1.3 MARPOL

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution by ships, from operational or accidental causes, of the marine environment. The Convention includes regulations aimed at preventing and minimizing pollution from ships and currently includes six technical Annexes. Annex VI covers the Prevention of Air Pollution from Ships and it establishes limits on sulphur oxide and nitrogen oxide emissions from ship exhausts, prohibiting deliberate emissions of ozone


Photo: Viking Line

Photo: Fjordline

Figure 15: Viking Grace and MS Stavangerfjord

depleting substances. It also sets designated emission control areas with more stringent standards for SO_X, NO_X and particulate matter (ECAs) (IMO, 2013).

5.1.4 International Gas Carrier Code (IGC code)

The IGC-code applies to gas carriers constructed on or after 1/7/1986. The code provides an international standard for safe transportation by prescribing design and construction standards. Older carriers either have to comply with the Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (GC Code) or the Code for Existing Ships Carrying Liquefied Gases in Bulk (if the carrier was constructed before 31/12/1976) (MOW, 2012).

5.1.5 International Code for the Construction of Gas Fuelled Ships (IGF code)

There are no formal IMO rules concerning LNG fueled vessels other than the IGC code that permits LNG carriers to use their boil-off gas as a fuel. The publication of an international code for the construction of gas fueled ships is expected to be published no earlier than 2013-14. As vessels are not permitted to use an oil fuel with a flashpoint of less than 60° (SOLAS, II-2, part B – prevention of fire and explosion), an interim guideline was published by the IMO, formally known as Resolution MSC.285(86). The IGF code will not include the bunkering of LNG (MOW, 2012).

5.1.6 Class rules

Seagoing vessels are all built according to class rules set by a classification society. With the introduction of the first LNG carrier, the classification societies developed specific rules for the construction and safe operation of LNG carriers. To ensure the safety and technical integrity of propulsion systems fueled by LNG, additional rules are being developed.

The International Association of Classification Societies is a supra-structure that publishes the Unified Requirements, from which requirement M59 is of particular relevance: the Control and Safety Systems for Dual Fuel Diesel Engines (MOW, 2012).

5.1.7 European Maritime Safety Agency

The European Maritime Safety agency (EMSA) aims to provide a consolidated version of possible common EU-wide checklists, guidelines or standards for LNG bunkering. In May 2013 EMSA published a tender for a study on standards and rules for bunkering of gas-fuelled ships. The first results are expected in December 2012. The tender contains 4 tasks (EMSA, 2012):

1. Provide a detailed description of the standards, regulations and guidelines related to LNG bunkering
2. Provide a gap analysis on the requirements of current and on-going LNG related rules
3. Provide a consolidated version of a proposed for common EU-wide guidelines or standards for LNG bunkering
4. Present preliminary results of tasks 1-3 to stakeholders and member states

Two working groups have been created—a group of EU pioneer ports and bunker operators and a group of ship and ferry operators. These groups will act as reference groups for study and potential new LNG related initiatives by EMSA.

5.2 Ship-to-shore and ship-to-ship transfer standards

The regulatory framework for seagoing vessels does not include the transfer of materials. Advice and support for these operations are captured in current operating standards and best practices. These are prepared by societies such as the Society of International Gas Tanker & Terminal Operators (SIGTTO) and the Oil Companies International Marine Forum (OCIMF).

An important document for LNG is the Ship-to-Ship Transfer Guide (Liquefied Gases) by OCIMF/SIGTTO, which was originally written for the transfer of LPG at sea. Another important reference is the LNG ship-to-ship transfer guidelines. This covers the transfer of LNG from carriers at anchor, alongside a shore jetty or underway (MOW, 2012).

Several publications that cover ship-to-shore bunkering are available, for example:

- Safety in Liquefied Gas Marine Transportation an Terminal operators
- Ship-Shore Interface–Safe Working Practices for LPG & Liquefied Chemical Gas Cargoes
- LNG operations in Port Areas, ESD arrangements and Linker Ship-to-Shore Systems for Liquefied Gas Carriers

Another applicable OCIMF regulation is the International Safety Guide for Oil Tankers & Terminals (ISGOTT).

A procedural description on LNG ship-to ship-bunkering has been carried out by the Swedish Marine Technology Forum[1]. The document's scope is LNG ship-to-ship bunkering procedures in a port environment with concurrent cargo and passenger handling in progress.

5.2.1 International organization for standardization (ISO)

ISO produces International Standards, Technical Reports, Technical Specifications, Publicly available Specifications, Technical Corrigenda and Guides. Two publications, "ISO 28460:2010 – LNG ship to shore interface and Port Operations" and "ISO13709:2003 – Centrifugal pumps for Petroleum, Petrochemical and Natural Gas Industries" relate to the use of LNG. A working group (ISO TC67/WG10) is developing guidelines (in the form of a technical report) for systems and installations that will use and supply of LNG as fuel to ships. Results are expected in March 2013 (MOW, 2012).

5.3 Global initiatives by involved parties

From a diverse group of companies and institutions, initiatives are currently underway to take the lead in the implementation of LNG as marine fuel.

5.3.1 World Ports Climate Initiative

The International Association of Ports and Harbours (IAPH) organizes various international workgroups within the World Ports Climate Initiative (WPCI, 2012), each focusing on a specific aspect of the environment in the port sector. WPCI is supported by the European Sea Ports Organization (ESPO) and EMSA. The members of these workgroups are mainly port authorities. The WPCI LNG workgroup endeavors to be the forum for the early standardisation processes between ports and to develop guidelines and/or assess the possible impact at ports with regard to infrastructure, safety requirements for bunkering and the legal aspects on the use of LNG. WPCI has covers four main areas:

1. Bunker checklists and guidelines for the accreditation of LNG bunkering companies
2. Give guidance to harmonize the approach of risk perimeters
3. Provide clear and unbiased information for the public
4. Create an information share point between ports

5.3.2 SIGTTO

SIGTTO is concerned that many people who may potentially be involved in the LNG infrastructure, such as bunkering suppliers and crew on LNG-fueled vessels, could lack relevant knowledge about the properties and hazards of LNG. SIGTTO states that an incident on an LNG-fueled vessel will affect the wider LNG industry, which has an almost zero incident track record at the present. Particular areas of concern are training of crew and bunker suppliers, simultaneous operations and ship design. SIGTTO is involved with the Ship-to-Ship Transfer Guide (Liquefied Gases). The LNG Ship Fuel Safety Advisory Group promotes the use of natural gas with an equivalent level of safety for the large scale LNG transport industry. The Advisory Group supports stakeholders in the marine gas fuel industry, identifies issues and provides guidance and information based on the experience of group members (MOW, 2012). At present, SIGTTO is:

- Participating in IMO work and corresponding groups of the IGF code
- Part of the ISO TC67 working group 10
- Reviewing of IGC Code

[1] Also: FKAB Marine Design, Linde Cryo AB, Det Norske Veritas AS (DNV), LNG GOT and White Smoke AB

5.3.3 North European LNG Infrastructure Project

In 2012, the EU founded a study on the feasibility for an LNG filling station infrastructure in North Europe[2]. A brief overview of the permit processes and consultation with authorities and the general public is provided. An important part of this study contains recommendations made on several aspects of the LNG, three of which focused on the permit process (MOW, 2012).

5.3.4 Methods for provision of LNG as shipping fuel in Flemish ports

The Flemish Department of Mobility and Public Work (MOW) commissioned a report on the methods for the providing LNG as marine fuel in Flemish ports, subsequently referred to as the Flemish Study. This study also made some recommendations for the necessary regulatory framework. These recommendations have been adopted by the recently founded Flemish LNG expert group, chaired by MOW.

5.4 Regulations for onshore activities

5.4.1 International standards and best practices

5.4.1.1 European Committee for Standardization (CEN)

Most of the standards for land-based constructions in Europe are determined by the European Committee for Standardization. Some standards are voluntary, others may be mandatory under EU law. A list of standards that apply to LNG can be found in the Flemish Study (MOW, 2012).

5.4.1.2 The Code of Federal Regulations (CFR)

CFR standards are produced by different American Societies, such as the US Department of Transportation Pipeline and Hazardous Materials Safety Administration and others. An overview of LNG applicable regulations can be found in the Flemish Study (MOW, 2012).

5.4.1.3 The National Fire Protection Association (NFPA)

The following NFPA standards apply to LNG facilities:

- NFPA 59A—Production and Storage of LNG
- NFPA 30—Flammable and Combustible Liquids Code

5.4.1.4 The American Petroleum Institute (API)

Most of the standards and recommended practices from the API are dedicated to a single type of equipment. The Flemish Study (MOW, 2012) provides an overview of the relevant documents.

5.4.2 European legislation

5.4.2.1 Provision of Public Consultation

The national regulations concerning the public consultation process and making information available to the public are governed by the Environmental Impact Assessment (EIA) Directive (85/337/EEC). According to this Directive each Member State can determine if an Environmental Impact Assessment is compulsory. The guidelines define minimum requirements for public consultation. The provisions for public participation in the EIA Directive were strengthened by the introduction of Directive 2003/35/EC, which included early public consultation in the decision-making procedure (DMA, 2012).

5.4.2.2 The Seveso Directive

The Seveso Directive (96/82/EC) is the main piece of EU legislation dealing specifically with the control of onshore major accidents involving dangerous substances. The Directive implements two tiers of control:

- Lower tier (Seveso I)—Covers establishments which hold more than 50 tonnes of LNG
- Upper tier (Seveso II)—Covers establishments above 200 tonnes
(DMA, 2012)

[2] The main partner in the study was the Danish Maritime Authority, other partners were Bureau Veritas, Energigas Sverige, Fluxys LNG, Gasnor, Gazprom, GL, Gasunie, Gazprom, Lauritzen Kosan, MAN, Flemish department of Mobility and Public Works, Norwegian Ministry of Trade and Industry, Hirtshals Havn, Port of Rotterdam, Port Szczecin-swinoujscie, Port of Zeebrugge, Finnish Transport Safety agency, Den Danske Maritime Fond.

The Directive also obliges competent authorities to for example, examine the Safety Report, to communicate with the operator and the public, and to identify any possible domino effects following a major incident.

5.4.2.3 International Carriage of Dangerous Goods by Road (ADR)

The European agreement concerning the international carriage of dangerous goods by road (ADR) has been adopted by most of the 56 members of the United Nations Economic Commission for Europe (UNECE or ECE) and incorporated into the various national legislations. The transportation of LNG is subject to the conditions outlined in Annexes A (construction and labelling) and B (construction of the truck) (MOW, 2012).

5.5 Regulations for transporting LNG via inland ship-based activities

The following section provides a brief overview of the two main governing bodies, the regulatory framework and standards governing the transportation of LNG via inland vessels.

5.5.1 The Rhine Vessel Inspection Regulations (RVIR)

The Central Commission for the Navigation on the Rhine (CCNR) publishes its technical rules in the RVIR, which has become Europe's main technical reference on the subject. The regulations have been partly transposed into other national regulations by UNECE and the European Community (2006/87/EC). As a result, the CCNR recognizes the validity of Community certificates on the Rhine, while Rhine certificates are also been recognized on all EU waterways. Future development of Rhine and EU regulations are expected to evolve in tandem so as to remain identical.

RVIR regulation is stringent but also flexible, with a range of implementation options including:

- Transitory provisions—Takes into account of the vested rights of older vessels
- Temporary 3-year provisions—CCNR may test a new rule for a period 3 years after which the rule will be either abandoned or adopted
- Waivers—Vessel operators may use alternative technology not covered by the regulations other if comparable guarantees can be provided (MOW, 2012)

5.5.2 The international carriage of dangerous goods by inland waterways (ADN)

In 2000, the United Nations Economic Commission for Europe (UNECE) produced a European agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN). The regulations outlined in the annexes of the ADN contain provisions concerning the carriage of dangerous substances including the requirements and procedures for inspections, issuing certificates of approval, recognition of classification societies, monitoring, training and the examination of experts.

Inland shipping legislation—ADN, RVIR and European Directive—contain specific information about the use of fuel in a shipping engine. As the legislation states that the use of fuel with a flashpoint below 55°C is not permitted, propulsion by LNG is prohibited in inland waterways. The transportation of LNG as cargo is also prohibited. ADN legislation only applies to inland ships that are certified for the transportation of dangerous goods by inland waterways. Ferries and other ships that do not transport dangerous goods do not have to comply with ADN legislation. Despite the fact that the current European legislation prohibits the use of LNG as a fuel, there are already inland ships inside the European Union that are using LNG as marine fuel. To allow LNG-fuelled ships on national waters, the Dutch authorities introduced a temporary exemption through UNECE / CCNR, which implies that the vessel obtaining the exemption can operate in all EU countries. This temporary exemption is possible because of the waiver arrangements available in the RVIR that provides ship owners and builders the opportunity to implement alternate, equivalent arrangements. Any proposed exemptions must demonstrate that the alternative arrangement is at least as safe as the original arrangements governed by the RVIR. One disadvantage of the waiver principle is two sister ships cannot use the same waiver as they are not considered unique (MOW, 2012).

5.5.3 International Safety Guide for Inland Tank-barges and Terminals (ISGINTT)

The OCIMF, together with other stakeholders for inland waterways (such as the CCNR), developed the International Safety Guide for Inland Tank-barges and Terminals (ISGINTT). The ISGINTT is not intended to replace or amend current legislation as ADN and RVIR, but to provide additional recommendations. The CCNR supports the ISGINTT as the principal industry reference manual for the safe operation of tankers and the terminals that serve them (MOW, 2012).

5.6 Conclusion

As the permitted sulphur emissions inside an ECA will be further restricted by 2015, an enormous amount of infrastructure redevelopment and associated activities will be required to facilitate the use of LNG as marine fuel. The main parties involved in the shipping industry are urging the adaption of existing legislation and standards to support the required changes. A major consideration is the desire to maintain the good safety record that LNG has acquired over the years. Although this much needed, safety-focused development is vulnerable on two fronts. First-adopter organisations could be hampered if legislative bodies are not sufficiently involved with currently developing projects. Conversely, too many single-party initiatives could lead to a proliferation of rules and standards that may not be in line with the eventual legislation. Open and constructive communication between all stakeholders is viewed as crucial to avoiding both of these potential outcomes.

Photo: Shell

Shell's LNG powered barge Greenstream

6 Bunkering procedures

6.1 Present status

As described in Chapter 5 there are no current international standards or guidelines for bunkering LNG as fuel. A number of LNG transfer guidelines are available, for example from the SIGTTO, but these guidelines are limited to LNG cargo transfer and are not applicable for bunkering LNG due to the following transfer arrangements:

- LNG transfer takes place in dedicated separated areas such as special harbours for tanker
- Trained crews and personnel handle the LNG
- No simultaneous cargo handling operation
- No requirement to consider the effect on third parties such as passengers

Additionally the existing transfer guidelines are limited to the ship-to-ship transfer of LNG and do not take into account the range of possible bunkering processes including:

- Shore-to-ship
- Truck-to-ship
- Connection and disconnection of mobile fuel tanks

6.2 On-going international developments

The most important international developments with respect to LNG rules at present are the development of the IGF Code by the IMO sub-committee BLG and the development of Guidelines for bunkering LNG by the ISO Technical Committee 67 Working Group 10. As the IGF code will only include requirements for the bunker station, all other aspects related to the LNG bunkering process were addressed by the ISO TC 67 WG 10, which was established to develop the "Guidelines for systems and installations for supply of LNG as fuel to Ships". The working group will produce the final set of guidelines by 2014, with a high-level draft version of the guidelines available during the first half of 2013.

The objectives of the ISO guidelines are to standardize the interface between ship and bunkering facilities, connection and disconnection, the emergency shutdown procedures and the LNG bunkering process control, to ensure that an LNG-fuelled ship can refuel safely and reliably regardless of the type of bunkering facility. The LNG bunkering interface comprises the area of LNG transfer and includes manifold, valves, safety and security systems, and the personnel involved in the LNG bunkering operations.

The structure of the ISO guidelines is as follows:

1. Scope
2. Normative references
3. Terms and definitions
4. General principles
5. Properties and behaviour of LNG as fuel
6. Safety
7. Functional requirements for LNG bunkering system
8. Requirements to components and systems
9. Training
10. Requirements for documentation

6.3 National initiatives and solutions

In addition to the on-going international development of rules within different European countries, bunkering procedures have been developed and are allowed subject to special permission:

- Many of the existing LNG-fuelled vessels currently operate in Norwegian waters. They are bunkered via truck or local bunkering stations. Under normal conditions general permission is given in the law and is based on risk analysis. Under special conditions permission is given from Norwegian Directorate for Civil Protection and the local fire brigade.

- During the LESAS project the current framework of regulation, codes and standards for the establishment of a small scale LNG supply chain, and using LNG as fuel for shipping and vehicles in the Netherlands has been investigated for various bunkering operations.

- Germanischer Lloyd (GL) undertook a study on behalf of the Federal Ministry of Transport, Building and Urban development ("Feasibility study for bunkering liquefied gas within German ports") to investigate the current regulatory framework and safety requirements for a safe bunkering of LNG within German ports. One of the results of the study is a draft report on safety operations for LNG bunkering within ports.

- In March 2013 the European Maritime Safety Agency (EMSA) published the "study on standards and rules for bunkering of gas-fuelled ships" carried out by GL. The objective of the investigation is to provide an overview of the existing rule framework, the current development of rules regarding bunkering gas-fuelled vessels, and to identify a possible requirement for a European edict for regulating LNG bunkering.

6.4 Conclusion

At present the development of the ISO TC 67 WG10 PT1 LNG bunkering guidelines seems to be the most important step towards the international regulation of bunkering LNG as fuel for shipping, taking into account a common risk assessment approach as well as functional and safety requirements for the transfer system. A first draft of the guidelines will be available in March 2013. It remains to be seen if these guidelines will provide the necessary guidance to ensure safe LNG bunkering within normal port limits and during normal harbour operation of vessels including:

- At each harbour within the port
- During cargo loading and unloading
- During passenger embarkation and disembarkation

7 Bunkering and navigational safety evaluation

7.1 Introduction

To ensure safe bunkering for LNG, the external risks for the bunkering operation itself and any environmental risks which might result from the bunkering process should be evaluated. To identify possible risks, an evaluation of an LNG-Vessel operating in the Port of Hamburg has been carried out during the project. The basis for the risk evaluation of an LNG infrastructure described below forms a HAZID—to identify worst case scenarios and a navigational safety study for the detailed risk assessment. The aim of this showcase evaluation is to report findings, exchange experiences and discuss ways to encourage stakeholders, such as ports, terminal operators or shipping companies, to consider switching to LNG and create a new market.

As there is no LNG infrastructure in the Port of Hamburg at present, LNG must be delivered to the port. The most likely supply chain for the Port of Hamburg is shown in Figure 16. Firstly, LNG will be transported to Hamburg from a large LNG Import/Export terminal in Europe (for example, Zeebrügge) or from a small scale LNG production plant in Northern Europe via an LNG Feeder vessel. Because the distance to an LNG source is longer than considered practical, it was assumed that an intermediate LNG terminal will be constructed in Hamburg to store and redistribute LNG in the harbour. This intermediate terminal will be the basis for the LNG bunker vessel, which distributes the LNG to the respective receiving vessels. Given normal operating procedures for such vessels, it is assumed that a bunker vessel will normally only transport the fuel ordered by one customer (delivery on demand).

7.2 HAZID

For the purposes of hazard identification (HAZID), bunkering from an LNG bunker vessel to a receiving container feeder vessel was studied to identify the main risks associated with LNG bunkering operations in the harbour of Hamburg. An LNG bunker vessel design from TGE, developed as part of the BunGas-project, and a GL LNG container feeder vessel were chosen for the investigation.

The bunker vessel is designed to handle and transport LNG and marine gas oil (MGO) and can also deliver LNG and marine gasoil simultaneously to a receiving vessel. The bunker vessel is equipped with a special transfer arm, comparable to a hard arm solution, carrying the piping and all relevant systems for the transfer of LNG and MGO. The transfer arm has an operating distance of 20 m and is supported within the ship structure between the LNG storage tanks.

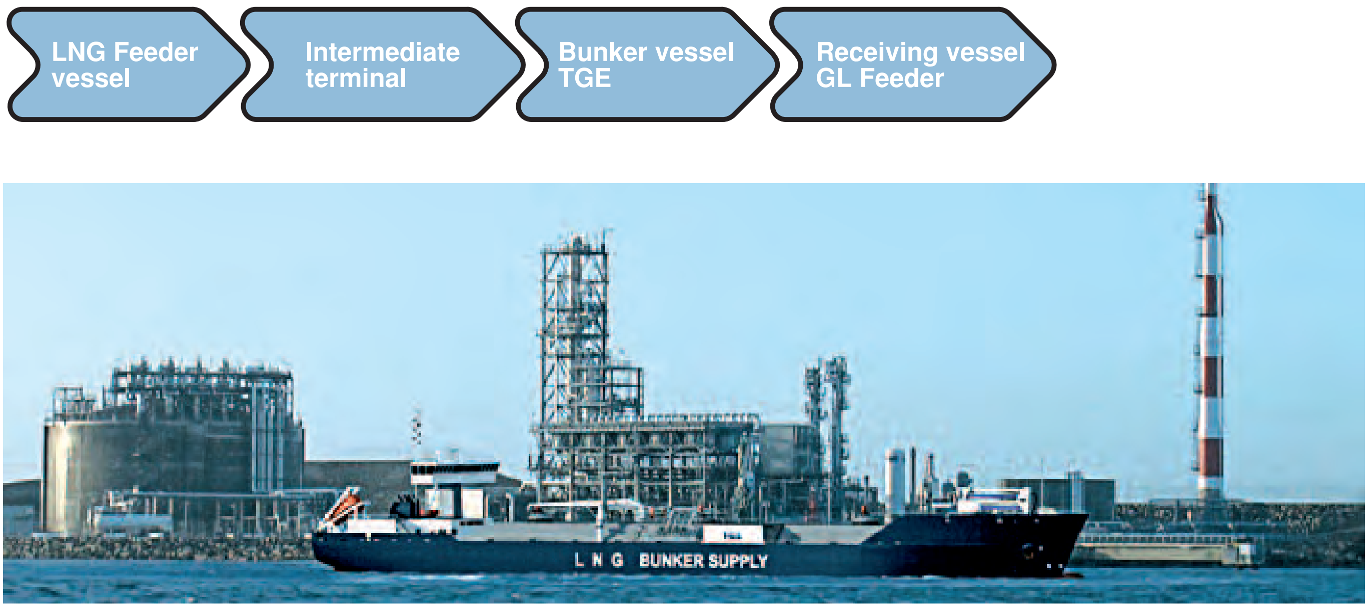


Photo: Germanischer Lloyds/CNSS

Figure 16: LNG supply chain for the example Port of Hamburg

Movements of both ships during fuel transfer can be controlled by an automatic adjustment control system that equalizes all relative movements.

The principle dimensions of the TGE bunker vessel are as follows:

Length overall	98.60 m
Length b.p.	93.00 m
Breath moulded	14.20 m
Depth moulded	7.60 m
Draught (design)	4.20 m
Deadweight	2050 t
Cargo tank volume LNG (100%)	3000 m^3
Cargo tank volume MGO (100%)	400 m^3

Photo: GLI/CNSS

Figure 17: Gas-fuelled feeder container vessel

The bunker vessel will bunker an LNG-fuelled container feeder. For the purposes of this study the design of the GL LNG container feeder was used (see Figure 18).

The principle dimensions of the container feeder are as follows:

Length overall	166.15 m
Length b.p.	155.08 m
Breath moulded	25.00 m
Depth moulded	14.20 m
Draught (design)	9.50 m
Deadweight	18300 t
Capacity	1240 TEU
Bunker tank volume LNG (100%)	670 m^3

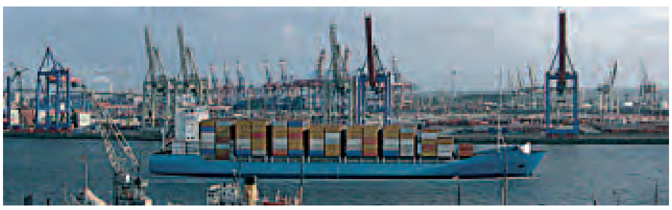


Photo: GLI/CNSS

Figure 18: Gas-fuelled feeder container vessel

The bunker station on board the receiving vessel was located beside the superstructure on the poop deck. This ensures that the bunker station is not located in the cargo area, bunkering operations will not disturb cargo operations, and it is a short distance to the storage tank.
For the purposes of this investigation, it was agreed that a berth with a lot of passing traffic should be used. Another factor to consider for the investigation was the higher speeds for manoeuvrability that vessels must maintain when entering the Parkhafen. Berth Athabaskakai 8 was identified as the most appropriate berth for the study (see Figure 19).

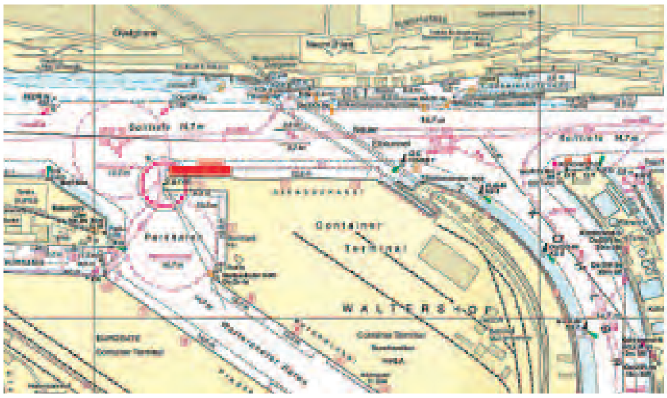


Figure 19: Location of bunkering in the port of Hamburg (nautical chart)

7.2.1 HAZID results

To identify possible systemic weaknesses, different operating conditions are examined during the investigation. It was assumed that all critical failures would occur during normal bunkering operations. The FMEA team concluded that during the start-up, shut-down or ESD, the risk was equal to or lower than the risk associated with normal bunkering operations. The investigation also looked into where the main hazards can occur during LNG bunkering.

For the assessment of different failure modes in the HAZID, understanding expected consequences, as well as the probability of their occurrence, are fundamental. For the assessment of the HAZID results, a ranking of the detected failures was produced based on a number of evaluating procedures that were available. The assessment by means of a criticality matrix, as mentioned in IEC 60812, was adopted.

Detected failures are shown in the matrix based on the severity of the failure and the probability of occurrence. These result help identify acceptable and unacceptable regions. It should be noted however, that there is no universally accepted definition of criticality. Criticality is general defined by analysts working on individual projects and as a result, definitions may differ considerably.

Severity is ranked from 1 - 5, with 5 representing the highest severity (fatalities and/or loss of system/other systems). The probability of occurrence is also represented in ascending order along the matrix Y-axis.

During the HAZID, 41 failures were investigated. An assessment of the occurrence, severity and detection of those failures was carried out in two stages:

- First stage—No considering of safety measures (initial rating - Figure 20)
- Second stage—All existing safety measures (monitoring, safety valves, alarm and shut-down systems) were taken into account (revised rating - Figure 21)

After entering all failures into the revised criticality matrix (consideration of all safety measures), it was possible to identify where a failure or leakage would have the most critical impact during LNG bunkering. The failures in the criticality matrix were cross-checked against a failure list, where all failures were listed according to their individual Risk Priority Number (RPN). This cross-check also considers the detectability of the failures in addition to the severity and occurrence of the failures. The approach adopted is not illustrated in this report.

The results indicate that the most critical situations, involving personal injury, would occur in the event of a large LNG leakage. However the likely occurrence of incidents involving personal injury was considered to be the same as with conventional oil bunkering.
The matrix highlighted five high risk failures, which are considered to be an unacceptable risk, and relate to the following events:

			Probability of Occurence				
			1	2	3	4	5
			not possible	>100 Years	10 to 100 Years	1 to 10 Years	< 1 Year
Severity	1	No effect				1	
	2	Disturbed operation			2	1	6
	3	Damage or breakdown of system			4	4	1
	4	Injured people major damage of other system		1	7	3	2
	5	Fatalities loss of other systems		6	2		1

Figure 20: Distribution of failures (initial rating)

			Probability of Occurence				
			1	2	3	4	5
			not possible	>100 Years	10 to 100 Years	1 to 10 Years	< 1 Year
Severity	1	No effect			1	1	1
	2	Disturbed operation		1	5	1	8
	3	Damage or breakdown of system		4	4	2	1
	4	Injured people major damage of other system		1	5	2	
	5	Fatalities loss of other systems		2	2		

Figure 21: Distribution of failures (revised rating)

1. Loss of bunker connection during a bunkering operation resulting in a large LNG spill.
   Mitigation measures: To avoid the probability of failures during connection a QC/DC mechanism should be considered. Furthermore the Emergency Shut Down times should be as short as possible to minimise the amount of leaking LNG.

2. Communication problems during the bunkering operation may lead to critical situations.
   Note: The severity of this failure is moderate, but the occurrence is frequent. This failure is not considered different to conventional bunkering operations.
   Mitigation measures: Bunker procedures and checklists should ensure sufficient communication.

3. Crew member falls over board (this failure is not considered different to conventional bunkering operations).
   Mitigation measures: The bunker vessel must be able to transfer bunker crew to the receiving vessel safely.

4. Large objects falling from the terminal will hit the bunker vessel. Damage to the storage tank not expected but damage to the bunker line is possible.
   Mitigation measures: To avoid the probability of failures during connection a QC/DC mechanism should be considered. Furthermore the Emergency Shut Down times should be as short as possible to minimise the amount of leaking LNG.
5. Side collision of a passing vessel into the bunker vessel (90° angle). Damage to the storage tank expected.
   Mitigation measures: The probability for a collision can be lowered by using defined areas for bunkering operations or implementing traffic restrictions.

The analysis highlighted that the most critical situations could be expected in the event of a large LNG leakage. The most critical situation occurs as a result of damage to the shell of the storage tank in the bunker vessel, which can occur in the event of a collision. To assess the risk and impact of a serious collision in the LNG supply chain at the Port of Hamburg, a detailed navigational study was undertaken.

7.3 Traffic analysis

To conduct a detailed navigational study within the Port of Hamburg, it is first necessary to establish realistic traffic conditions. This was achieved by using AIS (Automatic Identification System), a wireless transmission system used for collision avoidance and to support the vessel traffic service (VTS). AIS supports the exchange of ship-related data between vessels and land-based traffic services or port authorities.

AIS-Data provides ship-related information both in real-time for collision avoidance and navigational support, and also for off-line analysis of historical AIS recordings. The analysis of recordings for a specific sea region provides valuable information about actual traffic routes used and the associated shipping data.

One possible option for analysing AIS-Data is using Graphical Analysis. In its simplest form, all positional information that is recorded over a certain time-span can be recorded on a sea chart (see Figure 22:). Graphical displays can also be refined by the application of filters. For example, filters can be applied to restrict the display to certain ship types or to select vessels based on certain parameters, such as different draught or ship size.

Another possibility for analysing historical AIS-Data is a Gate Analysis. With this type of analysis the ship traffic is evaluated at a specific fixed line, or a gate, which in most cases lies perpendicular to a shipping route. Only those vessels crossing the line are investigated in detail (see Figure 22:).

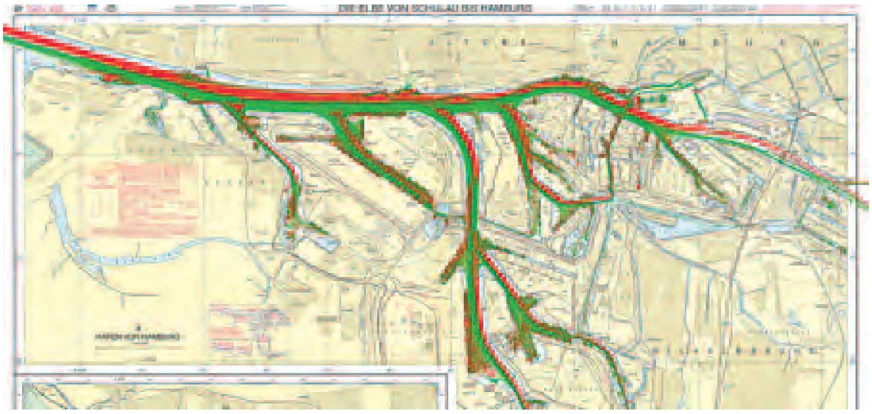


Figure 22: AIS-tracks for 2011 - Green tracks present south going ships and red tracks north going

7.3.1 Traffic analysis of the Port of Hamburg

The AIS-Data analysis in this project is based on AIS-Data recorded within the study area of Port of Hamburg during the months of January, April, July and October of 2011, and represents 109 days of ship movement. It should be noted that a number of ships (mainly smaller ships) are not included in this analysis. The next figure provides a simple graphical image of AIS-Data tracks within the study area of the Port of Hamburg.

Ships / Position of Gates

Gate No	1st coordinate		2nd coordinate		Width of the Gate	Sensitivity of direction	Total ships, normalised for 1 year
	latitude	longitude	latitude	longitude			
Gate 1	53°32.7´N	9°54.3´E	53°32.4´N	9°54.3´E	0.3 nm	30°	27636
Gate 2	53°32.2´N	9°55.8´E	53°32.4´N	9°56.2´E	0.3 nm	30°	17503
Gate 4	53°20.6´N	9°56.8´E	53°30.7´N	9°57.2´E	0.4 nm	30°	8325
Gate 5	53°32.6´N	9°56.1´E	53°32.4´N	9°56.1´E	0.4 nm	30°	13120

Table 1: Position and information of the gates

Gate analyses have been performed at five locations in the Port of Hamburg. Gate 1 is close to the jetty of Athabaskakai. Gate 2 detects the passing traffic from and to Köhlbrand. Gate 3 detects the shipping traffic going in and out of the Waltershofer Hafen (results at Gate 3 have not been considered within this analysis), Gate 4 detects the traffic passing the Rethe from and to the Kattwykhafen, and Gate 5 detects the traffic passing the Ferry Terminal Altona. These data are used as input parameters for the quantitative risk assessment.

7.4 Quantitative risk assessment

The applied model for calculating the frequency of collision accidents in the Port of Hamburg involves the use of a so-called causation probability that is multiplied by a theoretically obtained number of collision candidates.

The causation factor models the probability that the officer on the watch has not reacted in time given that his vessel is on a collision course with another vessel. The numerical value of the causation probability is not a single value but often varies in different geographical locations.

Due to a causation factor (probability that last-minute recovery action will be unsuccessful) of 2.7 (Karlsson et al, 1998), a value of 10^{-5} seems to be adequate and is used for the following calculations of head-on collisions.

7.4.1 Considered situations for the LNG-Tanker

The following two scenarios have been evaluated for an LNG-Tanker (LNG-T) operating within the Port of Hamburg:

- Collision on transit within the Port of Hamburg:
  - For an LNG-Tanker the head-on collision is analysed for its route within Port of Hamburg. For the analysis the speed of the LNG-Tanker on its transit within Port of Hamburg was set to 8 kn, the average ship speed in this area.
  - Overtaking collisions, collisions at junctions as well as grounding are indirectly considered due to calibration with actual Collision Rates of the Port of Hamburg.
- Collision at berthing position:
  - The probability of being involved in a collision while off-loading at Kattwykhafen has also been analysed. The probable berth at Kattwykhafen provides some protection against such collisions, and this has been taken into consideration by reducing the vulnerable length to half the ship length.

7.4.2 Considered situations for the LNG-Bunker Vessel

The following scenarios for an LNG-Bunker Vessel (LNG-BSV) operating within the Port of Hamburg have been evaluated:

- Collision on transit within the Port of Hamburg.
  - For the LNG-Bunker Vessel a head-on collision along its route within the Port of Hamburg has been analysed. For the analysis the speed of the LNG-Bunker Vessel on its transit within Port of Hamburg was set to 8 kn, the average ship speed in this area.
  - Overtaking collisions, collisions at Junctions as well as grounding are indirectly considered due to calibration with actual Collision Rates of the Port of Hamburg.
  - The possibility that the LNG-Bunker Vessel has been hit while on service at a bunkering ground, alongside a jetty or by other vessel has been analysed for Athabaskakai and Ferry Terminal Altona (striking events).
  - Collision at Kattwykhafen while Waiting/Loading.

7.4.3 Head-on collisions in a shipping Lane

For head-on collisions, the probability can be calculated by using the meeting and causation probabilities for collisions. For head-on collisions, the meeting probability M can be estimated by the following formula given by Karlsson et al (1998). The results are provided in section 7.5 for a single entry/exit operation within the Port of Hamburg.

$$M = 2 \cdot L \cdot N_N \cdot N_S \cdot \left(\frac{1}{V_N} + \frac{1}{V_S} \right)$$

L	Length of navigational legs
N_N and N_S	Number of movements (Number of vessels and one LNG-Tanker/LNG-Bunker Vessel journey per year in north/west - and south/east direction respectively)
Factor 2	The LNG-Tanker/LNG-Bunker Vessel is navigating the waterway twice, approaching and leaving the Port of Hamburg (Kattwykhafen) / Athabaskakai/Ferry Terminal Altona
	Length of LNG-Bunker Vessel approx. 100 m
w_f	Distance of floating object from normal average track (150 m/320 m)
$N_{transits}$	Number of vessel movements
$Time_{LNG-T/Bunker\ Vessel}$	Duration of LNG-Tanker moored at berth in Kattwykhafen/Duration of LNG-BSV at potential bunkering ground Athabaskakai/Ferry Terminal Altona for 2h, 4h and 6h of Bunkering Time for the LNG-Bunker Vessel

7.4.4 Striking at a berthing position

The estimation of striking frequencies f_{st} of passing vessels with the LNG-Tanker/LNG-Bunker Vessel at berth can be calculated by using a simplified International Navigation Association (PIANC) equation[3]:

$$f_{striking} = K \cdot R \cdot L_f / w_f \cdot N_{transits} \cdot Time_{LNG-T/BunkerVessel}$$

K	Constant, evaluated at 10^{-5} per transit
R	Probability of last-minute recovery action unsuccessful ($2*10^{-4}$)
L_f	Length of floating object profile along the channel. Considering the situation at Kattwykhafen a value of half ship length (70 m) has been used for the calculation.

[3] PIANC, Approach Channels – A Guide for Design, PTC II-30, June 1997

7.5 Collision rates for a realistic scenario

Based on the traffic data for the Port of Hamburg, the frequencies of a collision between the LNG tanker and another vessel, or the bunker vessel and another vessel, could be calculated according to formulas provided in section 7.4. A realistic showcase scenario, based on the single transit calculations, is summarized below.

The parameters of a showcase scenario are:

- LNG-Tanker weekly transit from the entrance of the Port of Hamburg to Kattwykhafen and return
- LNG-Tanker weekly off-loading/berthing time at Kattwykhafen of 24 hours
- LNG-BSV every other day transit Kattwykhafen to Athabaskakai and return (2 hours daily)
    - Bunkering time at Athabaskakai 4 hours
- LNG-BSV every other day transit Kattwykhafen to Ferry Terminal Altona (2 hours daily)
    - Bunkering time at Ferry Terminal Altona 4 hours
- LNG-BSV daily berthing time at Kattwykhafen of 18 hours (24h – 2h transit time – 4h bunkering time)

Realistic Show Case Scenario			
Unit	Berthing/ Loading/Transit	Accident Rate [1/a]	YBC [a]
LNG-Tanker Transit	(-)	8,87E-03	1,E+02
LNG-Tanker Off-loading	24	9,68E-07	1,E+06
LNG-BSV Transit Athabaskakai	(2)	7,32E-03	1,E+02
LNG-BSV Bunkering at Athabaskakai	4	9,35E-09	1,E+08
LNG-BSV Transit Ferry Terminal Altona	(2)	5,98E-03	2,E+02
LNG-BSV Bunkering at Ferry Terminal Altona	4	4,99E-09	2,E+08
LNG-BSV Berthing Time at Kattwyhafen	18	2,49E-06	4,E+05
Overall		2,22E-02	45

Table 2: Summary of a realistic showcase scenario

For the Port of Hamburg for collisions involving an LNG-Vessel (LNG Carrier or gas-fuelled vessel) in the collision scenario described, a collision rate of 2,22E-02 collisions/year has been calculated. The estimated time between collisions (TBC) (LNG Carrier or gas-fuelled vessel) is approximately 45 years. The combination of frequency and consequence defines the risk. The consequences of a collision are manifold and therefore difficult to predict.

7.6 Conclusion

The HAZID and the navigational study provide a first impression of the risk of LNG bunkering and handling in the harbour area of the Port of Hamburg. Using the HAZID the main risks can be identified. LNG leakages caused by a collision or as consequence of the bunkering process, will result in critical situations developing onboard the gas-fuelled and bunker vessels.

Further evaluations are required for a detailed, quantitative assessment of the risk of LNG-Vessel operation within a harbour area. This should include the identification of different discharge scenarios for specific tank types, dispersion calculations for the different discharge scenarios, dispersion calculation for leakage scenarios during bunkering itself, and so on.

8 Health and environmental aspects

8.1 Definition of LNG

Natural gas is a fossil fuel, meaning that the natural gas produced from the subsurface is derived from organic material deposited and buried in the earth millions of years ago. The main component of natural gas is methane (CH_4).

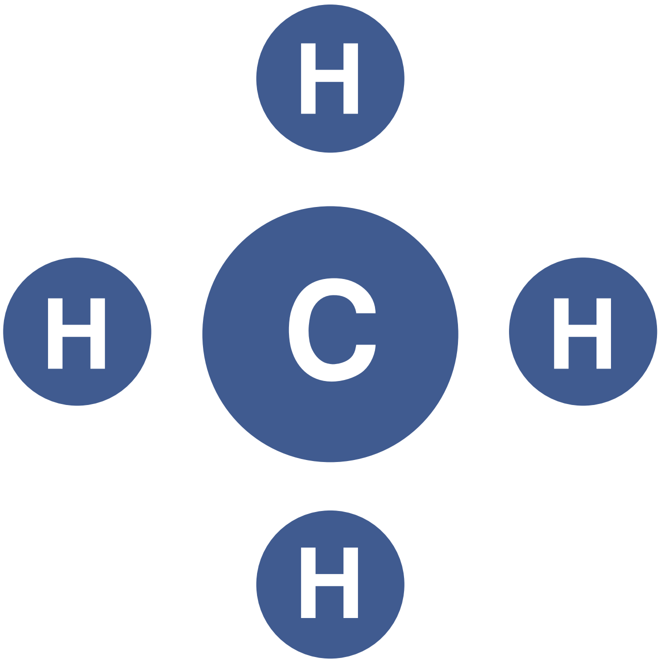


Figure 23: The methane molecule

When natural gas is produced, it includes many other molecules, like ethane, propane and butane. Small quantities of nitrogen, oxygen, carbon dioxide (CO_2), sulphur compounds, and water may also be present in natural gas. Liquefied natural gas (LNG) is natural gas that has been cooled to the point it condenses into a liquid, which occurs at a temperature of 160 °C at atmospheric pressure. The liquefaction process requires the removal of the non-methane components like carbon dioxide, sulphur compounds, water, butane, pentane and heavier components of natural gas to prevent the formation of solids. The liquefaction procedure reduces the volume of the gas by a factor of approximately 600. The energy content of 1 tonne LNG corresponds to 1,19 tonnes of diesel (IEA, 2005).

LNG is odourless, colourless, non-corrosive, and non-toxic. When vaporized it burns only in concentrations of 5 % - 15 % when mixed with air (Foss, 2007).

An alternative to LNG from fossil sources could be bio-LNG, which is produced from liquid manure or plant residuals. The advantage of bio-LNG is that its combustion does not add to the CO_2 budget because it stems from freshly fixated carbon. On the other hand, bio-LNG cannot currently be produced in sufficient quantities to be a viable alternative to LNG. Nevertheless, there may be opportunities to use bio-LNG for small scale local transportation such as harbour ferries or to blend it with LNG to reduce its CO_2 load.

8.2 Impact on the operation of machinery onboard ships

Overall, the use of LNG results in reliable and quieter engine operations. Using LNG as a fuel for 4-stroke engines causes significantly less wear and fewer deposits compared to using of HFO and that generally means a clean and tidy engine room (Mohn, 2011). The piston rings have a much longer service life and the engine lubricating oil for a lean gas engine has an operating time of more than 10,000 hours. This represents not only a significant operating cost saving but lessens the environmental impact of marine engines.

8.3 Health effects and risk potential

As LNG contains no toxic compounds a direct threat to human health can only be derived from its physical properties. If LNG is released, direct human contact with the cryogenic liquid will result in the skin being frozen at the contact point and may cause cryogenic burning. When LNG leaves a temperature-controlled container it begins to warm up, returning the liquid to a gaseous state. Initially, the gas is colder and heavier than the surrounding air. It creates a vapour cloud that can lead to asphyxiation in insufficiently ventilated locations. The vapour cloud may ignite if it encounters an ignition source while concentrated within its flammability range. This can of course also result in an explosion. If large volumes of LNG are released on water, the LNG may vaporize too quickly causing a Rapid Phase Transition (RPT). An RPT can only occur as a result of mixing LNG and water. RPTs range from small pops to blasts large enough to damage lightweight structures (Foss, 2007).

The potentially long term effects on human health from exhaust gas produced by LNG combustion are connected with its effects on the environment. In general, the impact of fossil fuel combustion products on health and the environment can be divided into local and global effects. Local effects involve the formation of so called secondary inorganic aerosols from NO_X and SO_X exhaust. When inhaled, these aerosols increase the risk for respiratory and circulatory diseases, and may even be responsible for premature death especially for high-risk groups like the elderly and people with respiratory problems, such as asthma, and other allergies (Corbett, 2007). Aerosols are also important for the local climate as they play a significant role in cloud formation and rainfall amounts. The local climate also has a significant impact on flora and fauna, and for agriculture.

When removed from the atmosphere, mainly by precipitation, the largest part of the nitrate and sulphate aerosols end up in water ecosystems where they cause two main problems. Nitrate is a nutrient that stimulates the growth of algae. Both sulphates and nitrates are acidifying compounds that lower the pH value of the rain water and produce acid rain, which can have negative effects on ecosystems.

8.4 Comparison of alternative fuels

As previously described, LNG undergoes a purification process during liquefaction. As a result LNG contains even less nitrogen and sulphur than natural gas, which already contains less of these chemical substances compared to heavy fuel oil (HFO, currently the most commonly used shipping fuel. LNG is burned in a lean mixture in combustion engines. The low temperature leads to a significant reduction in NO_X emissions. Furthermore, compared to oils CH_4 has a lower carbon to hydrogen ratio in relation to its energy content. As a result, CO_2 emissions are reduced compared to oil combustion, based on the assumption that the fuel is complete combusted. Since LNG does not require any treatment before combustion compared to fuel oils, there are no accumulations of sludge deposit. (Tellkamp, 2011)

The effective decrease of SO_X emissions from using LNG as opposed to HFO is close to 100 %. If HFO is used together with scrubber technology the SO_X emissions will be also reduced to almost zero. However, the sulphur that is removed from the exhaust gas by scrubbers has to be stored onboard and deposited later. Alternatively, the sulphur may be released as sulphur acid into the sea which causes acidification of the water. Using marine gas oil (MGO, sulphur content max. 0,1 %) will also result in lower SO_X emissions.

With respect to NO_X the situation is more complicated because the ambient air used in the combustion process also contains 71 % nitrogen. It's not just the type of fuel but also the type of engine that influences the formation and emission of NO_X. Both 4-stroke dual-fuel and lean-gas-engines operate with a high air excess ratio that lowers the combustion temperature in the engine, resulting in low NO_X production. Direct gas injection engines have higher NO_X emissions than the spark ignited dual-fuel and lean-burn gas engines. Direct gas injection will be used for large 2-stroke engines running on gas (Nielsen, 2010). Using LNG with dual-fuel diesel engines could, in the worst case, mean little reduction of NO_X exhaust compared to conventional diesel engines. However, emissions of NO_X may be reduced by a number of technologies. Diesel engine optimization can reduce the NO_X emissions by 37 % (Nielsen, 2010). With modern LNG engines a reduction of 85 % compared to HFO engines can be achieved (Buhaug, 2006).

LNG operating vessels emit virtually no particles directly, and as a result there are almost no primary organic aerosols, like soot in the exhaust gas, compared to engines burning oil based fuels. The contribution of LNG to the total particulates in ambient air is, however, not zero because of the emission of the precursors of particulates, as explained in section 8.3.The cleaner combustion process offered by LNG does mean longer intervals between maintenance operations.

The following table summarizes a comparison of the environmental effects of the different fuels LNG, HFO (with scrubber) and MGO (DMA, 2012). The listed emission reduction potentials refer to HFO engine emissions.

	LNG	**HFO with scrubber**	**MGO with SCR**
Tier III requirements (NO_X)	Reduction of 85 % compared to HFO engines	Need additional post treatment (e. g. SCR which reduces NO_X by 87 %)[1]	Reduction of 80 % compared to HFO engines
SECA requirements (SO_2) Advantages	SO_X emissions negligible	Sulphur emissions almost zero No need to retrofit or replace engine Use readily available HFO	Low sulphur emissions Small or no investment costs for retrofitting the engine
Direct PM emissions	Negligible	Significant reduction of PM content	Reduced PM emission
CO_2	Reduction up to approx. 25 %[2]	No decrease[3]	No decrease[3]
General disadvantages	Storage in cryogenic tanks. High ignition temperature which requires an additional ignition source	Produces waste but deposition infrastructure not . yet implemented Scrubbers must be IMO certified	Already high fuel price

[1] It is not yet proven if SCR can be applied together with scrubbers,
[2] without considering methane slip (GL, 2012),
[3] Operation of SCR and scrubbers will lead to increased fuel consumption

Table 3: Summary of the environmental effect of different fuels - LNG, HFO (with scrubber) and MGO (numbers refer to HFO combustion without treatment)

8.5 Global effects

The global environmental impact of LNG centres on its contribution to the greenhouse gas budget. Like all fossil fuels LNG increases the CO_2 budget in the atmosphere. On the one hand, LNG burns more effectively than HFO but on the other hand, the liquefaction of LNG means additional energy costs. As a result of LNG bunkering and combustion, methane may be released into the atmosphere which is 21 times more effective as a greenhouse gas than CO_2. To compare the contribution of LNG and HFO to greenhouse gas concentrations, the whole life cycle of each product must be analysed.

The major stages in the life cycle of LNG include:

- Exploration to find natural gas in the earth's crust and production of the gas for delivery to end users. Natural gas is usually, but not exclusively, discovered during the search for oil.
- Liquefaction to convert natural gas into a liquid state for transportation by ships
- Shipping the LNG in special purpose vessels
- Storage of LNG in specially made tanks
- Bunkering
- Combustion aboard ships

Jaramillo et al (2007) describe such a life cycle for LNG shipped to the USA and used for electricity generation. They found a total life cycle CO_2 emission of 18.6 kg/MWh produced electricity, with 17 % of these emissions attributed to production, processing, transmission, storage and distribution. The remainder was attributed to the combustion process. However, no methane slip was considered in the study, which has to be taken into account when using LNG for propulsion of ships. Methane slip from gas engines can be divided into two categories: operational emissions and engine emissions. Operational emissions could be the result of venting methane into the atmosphere due to certain operational conditions—methane released from refuelling or the methane released during storage on land, and so on. Engine emissions are only caused by methane slipping through the combustion chamber unburned. While operational emissions are affected by the design and operation of systems surrounding the engine, the engine emissions are caused by the engine concept, design and operating profile (Nielsen, 2010). The minimum CH_4 emissions can be achieved with high pressure LNG engines. This technology was, however, only available on a small number of ships in 2010 (Nielsen, 2010). In normal operation, lean gas engines emit much less methane than dual-fuel engines, with the newest models producing less than 1% methane slip.

To compare the greenhouse gas budget (usually denoted in CO_2equivalents) of LNG usage for ship engines with that of conventional fuels (mostly HFO), the complete life cycle of the fuel must be compared. In one such study, Bengtsson et al (2011) found that the reduction in greenhouse gas emissions was between 8 and 20% for LNG usage.

8.6 A local emission scenario for the city of Hamburg based on the replacement of oil-based fuels by LNG

According to market analysis conducted by Germanischer Lloyd (GL exchange forum 2012) concerning the future LNG demand for the Port of Hamburg harbour, the LNG demand for feeder vessels by 2020 was estimated to 400.000 m^3. On the basis of this estimation, it is possible to derive an illustration of how much pollutant emission could be saved, assuming that the LNG (following the specifications of Gasnor supplied LNG) would replace the approximately equivalent amount of HFO required to operate slow speed diesel engines.

To calculate the energy and carbon content of the LNG, the typical specification of LNG delivered by Gasnor was used. The energy content of the LNG volume is 6887 GJ. Together with emission factors in g/kWh compiled by Hulskotte and Denier van der Gon (2010) that take into account a weighted energy efficiency factor, emissions of CO_2, NO_x and SO_2 produced by HFO (that would be substituted by LNG) were calculated. With respect to estimating the SO_2 emissions, a sulphur content of 1% was assumed.

NO_x and CH_4 (methane) emissions from ship engines running on LNG were calculated using emission factors that were published by MARINTEK (Nielsen J. B. and Stenersen, D. 2010). The calculation of the CO_2 emissions was performed with the mass density and heating values taken from the LNG data sheet provided by Gasnor, and the efficiency factor for LNG engines taken from the MARINTEK study.

g/kWh	LNG	HFO
NO_x	1,1[1]	14,4[3]
SO_2		4,0[3]
CO_2	421,0[2]	634,0[3]
CH_4 (dual fuel)	15,6[1]	
CH_4 (lean-burn)	8,5[1]	
CH_4 (new lean-burn)	3,9[1]	

[1] MARINTEK, [2]calculated, [3](Hulskotte and Denier van der Gon 2010)

Table 4: Emission factors used to compare pollutant emissions for the LNG scenario

As LNG contains virtually no sulphur the total amount of 7658 tonnes SO_2 emitted by HFO-fuelled engines could be saved. Studies suggest that the obligatory reduction of 80% for NO_x in nitrogen emission control areas (NECA) can be achieved by substituting HFO with LNG (DMA, 2012). Assuming the NO_x emission factor for LNG found in the MARINTEK study for modern LNG driven vessels, a reduction of more than 90% in relation to the situation before TIER I of the NO_x reduction agreement was in force might be possible. This would also mean a reduction of fine particulate matter produced from gaseous SO_2 and NO_x due to chemical reactions in the atmosphere. This reduction, however, cannot be quantified without applying a comprehensive chemical-transport model because the amount of particulates produced depends on meteorological conditions like temperature, rain or UV-radiation, as well as on the presence of other chemical substances.

Although CO_2 emissions are reduced, this does not necessarily mean a reduction in greenhouse gas emissions because LNG engines emit CH_4, mainly as a result of the incomplete combustion of the fuel. There is also some loss due to the bunkering procedure which is, however, not taken into account here. Considering a time span of 100 years the global warming potential of CH_4 is 21 times higher than that of CO_2. MARINTEK determined CH_4 emission factors for dual-fuel diesel engines as well as for older and newer lean-burn LNG engines. Although for modern lean-burn gas engines a decrease of CO_2 equivalents by 23% was estimated and for old lean-burn engines a decrease of 9% was determined, an increase of 11% was estimated if dual-fuel diesel engines were used.

The results indicate that the decrease in greenhouse gas emissions is largely dependent on whether existing engines are retrofitted to use new technology, or new engines optimised for LNG use are introduced.

Over shorter time scales the effect of methane slip is even more significant, given the fact that the active time of CH_4 in the atmosphere is only about 12 years and the impact on climate of today's emitted methane decreases with time. To calculate the global warming potential of CH_4 in CO_2 equivalents for the next 20 years, the emitted CH_4 must be multiplied by 56 (http://unfccc.int/ghg_data/items/3825.php). The total CO_2-equivalents of the LNG exhaust is then calculated by adding emitted mass CH_4 multiplied by the equivalence factor to the mass emitted CO_2. Considering this only for modern lean-burn engines, a very small decrease could be achieved (1%) while with older lean-burn engines and dual-fuel engines the global warming potential for the next 20 years would increase (38% and 97% respectively). These numbers only apply to the estimated demand for LNG at Hamburg harbour in 2020 as described above, which has no significant global impact.

kT	LNG		HFO	Difference	
	20 years	100 years		20 years	100 years
CO_2 equivalents (dual fuel)	2395	1350	1215	1180	135
CO_2 equivalents (lean-burn)	1671	1102	1215	456	-113
CO_2 equivalents (new lean-burn)	1202	941	1215	-13	-274

Table 5: CO_2-equivalents emitted by different LNG combusting engines compared to emissions from HFO combusting engines

To illustrate the order of magnitude of the emission savings, the following table details the calculated exhaust for LNG and HFO for 2020 compared to the emissions of the Vattenfall power plant at Wedel near Hamburg for the year 2004 (The European Pollutant Release and Transfer Register; http://prtr.ec.europa.eu).

kT	LNG	HFO	Difference	Emissions by power plant
NO_x	2,1	27,6	-25,5	0,964
SO_2		7,7	-7,7	0,713
CO_2	760,5	1215	-454,5	1470

Table 6: Estimated emission reduction for the LNG scenario compared to annual emissions of a hard coal power plant (290 MW)

8.7 Summary

From a local perspective LNG offers many advantages for the environment compared to conventional marine fuels. Provided LNG is handled properly during storage and bunkering, there are neither direct risks nor long term effects for human health to be expected. In addition, through the significant reduction of NO_x and SO_2 emissions, the concentration levels of fine particulates and ozone, both of which are hazardous for human health, will decrease. Switching to LNG could help the shipping industry achieve and maintain the standards required to operate ships in the ECAs that are about to be established in the North Sea.

However, there are no guarantees that replacing mineral oils with LNG will reduce greenhouse gas emissions because this depends on the fuel consumption, or energy efficiency, the type of engine and the amount of methane escaping from the engine. To reduce greenhouse gas emissions, methane slip must be reduced and more efficient engines will be required. Reducing the operating speed of ships and introducing bio-LNG may help mitigate this problem.

9 LNG Market overview

9.1 The history of LNG

LNG has been produced commercially since 1940 as a method of transporting stranded natural gas to consumers where distribution via pipeline for various reasons was not possible. The market for LNG has been characterised by long term, large volume contracts between limited numbers of major players. Many of these players are states or state-owned companies with the LNG used as the main or alternative source of supply for natural gas to gas grid connected consumers. LNG has in principle never been sold directly to end users and the spot market of LNG has been infinite.

The price of natural gas has been closely connected to the price of crude oil, partly as a result of their shared history. Natural gas usually originates from “associated” fields, and is often produced together with crude oil. Since the economics of oil and gas production are very similar, the price of gas has traditionally been closely linked to the price of oil. However, more importantly, it was interfuel substitution, at the other end of the value chain, which really linked oil and gas prices for many years. Interfuel substitution simply means that two fuels could be used for the same purposes, for example for residential heating or electricity generation. Consequently, the similar economics of upstream production and the fact that oil and gas products have been close substitutes, resulted in the close correlation of oil and gas prices.

A similar correlation is also valid, according to Habib et al (2012), for pricing LNG for the long term supply contracts characteristic the LNG trade where the price of LNG is usually linked to crude oil.

In Figure 25 the correlation between natural gas and crude oil prices is plotted against the time period from 1984 until the end of the first decade of the 21st century. During that period the correlation between crude and natural gas is very close until 2005-2006 but after 2006 the prices begin to diverge. Two significant causes, discussed later in this chapter, have been identified:

- A price disassociation between crude and natural gas
- Increasing regional price differences for natural gas

9.2 Increase in availability

9.2.1 Global trends

During the last five to seven years there has been a significant increase in the availability of natural gas (NG) in the fuel market. This has resulted from a combination of new technical developments with respect to the exploration of so-called shale gas and significant investments in new production and distribution facilities for traditional natural gas sources in Australia, India, Qatar, Saudi Arabia, Iran, China and so on (see Table 7).
The total production of NG was about 3300 billion m^3 in 2011, with the total increase in production during the period 2006 to 2011 about 12,4% according to BP (2012). During the same time period the annual production of crude oil only increased with 1,7 %.

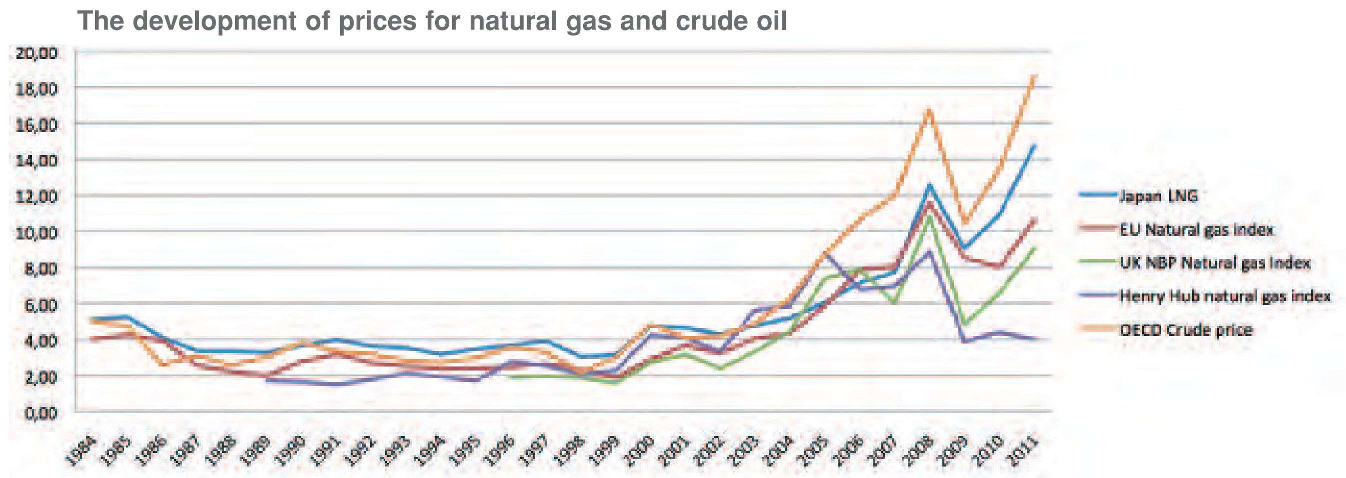
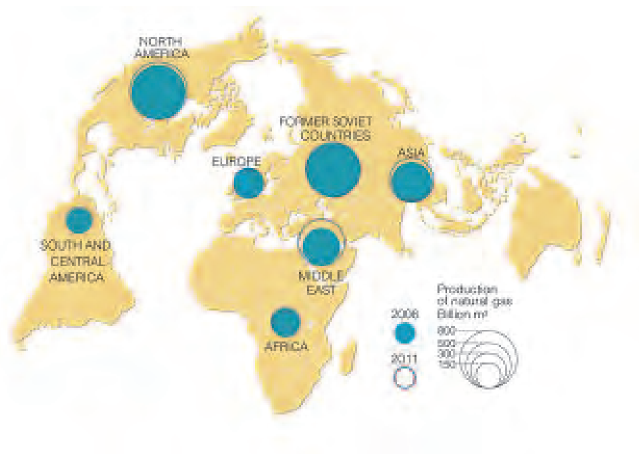


Figure 25: The development of prices for natural gas and crude oil (Source: BP Statistical Review of World Energy June 2012)

	Production 2006 (Billion m³)	Production 2011 (Billion m³)	Change
US	524,0	651,3	20%
Russian Federation	595,2	607,0	2%
Total Middle East	339,1	526,1	36%
Total Asia Pacific	382,4	479,1	20%
Total Africa	191,2	202,7	6%
Total S. & Cent. America	151,1	167,7	10%
Canada	188,4	160,5	-17%
Iran	108,6	151,8	28%
Qatar	50,7	146,8	65%
China	58,6	102,5	43%
Norway	87,6	101,4	14%
Saudi Arabia	73,5	99,2	26%
Algeria	84,5	78,0	-8%
Indonesia	70,3	75,6	0%
Netherlands	61,6	64,2	4%
Malaysia	63,3	61,8	-2%
Egypt	54,7	61,3	11%
Turkmenistan	60,4	59,5	-1%
Uzbekistan	54,5	57,0	4%
Mexico	51,5	52,5	2%
United Arab Emirates	49,0	51,7	5%
India	29,3	46,1	37%
United Kingdom	80,0	45,2	-77%
Australia	38,9	45,0	14%

Table 7: The top 20 NG producing countries 2011 (Source: BP 2012)

Figure 26 details the proven NG reserves from 1980 - 2011. By comparison to the period 2000 - 2006 there is a clear upturn in the proven NG resources in the period 2006 - 2011. It is anticipated that this trend will continue throughout 2012.



9.2.2 The shale gas revolution

Shale gas is found in layers of flaky shale rock and cannot be extracted like normal gas. The existence of this gas has been known about for a long time but it has not been possible to extract the gas from the shale rock in a commercially viable way. This changed in the last part of the first decade of the 21st century due to a combination in increasing gas prices and development of a new extraction technology called fracking. Extraction gas by fracking involves pumping huge amounts of water, mixed with chemicals, under high pressure into the layers of rock.

The United States (US) is at the forefront of the exploitation of shale gas, with recent developments

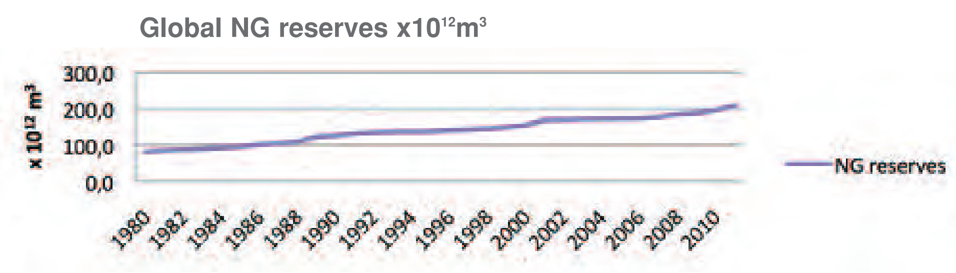


Figure 26: The development of proven reserves of NG (Source: BP Statistical Review of World Energy June 2012)

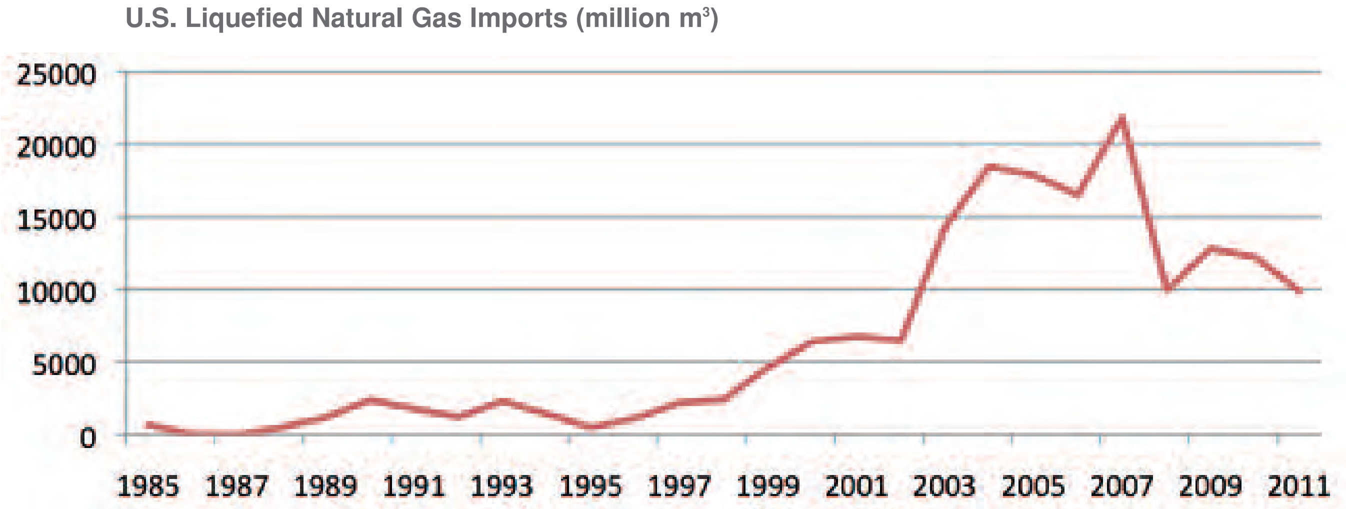


Figure 27: Annual US LNG Imports (Source: EIA website, 2012)

resulting in rapid increases their domestic production of natural gas. Previously the world's biggest net importer of natural gas, the US are set become a net exporter of the fuel. According to both BP, 2012 and IEA, 2012, 2012 is expected to be the first year the US produces more natural gas then is consumed domestically.

As a result US imports of both pipeline gas, and more significantly, LNG have declined to approximately 3% of the total import market in 2011 (see Figure 27). Since the US market was traditionally one of the main markets for LNG imports, accounting for about 10% of the total LNG import market in 2007, significant volumes of LNG are now available on the open market.

Shale gas is also available in other countries but the exploration of these resources is not as developed as in the US. China, for example, is presumed to have even larger shale gas reserves than the US and if these expectations actually materialise, China will have a significant impact on the natural gas and LNG markets. Over the last five years, China has gone from a natural gas exporter to become one of the largest natural gas importers in the world, with continuously growing natural gas consumption.

However, there are a number of obvious down sides to the current shale gas bonanza including the environmental and health concerns related to the explorations methods. Little research has been undertaken to establish the effects, both long-term and short-term, of the procedures and chemicals used in fracking. Aside from these two issues, compared to conventional gas extraction, more methane is discharged during the process, which is a powerful and damaging greenhouse gas. These three concerns resulted in the French authorities putting a temporary ban on fracking in 2011.

9.3 Regional pricing imbalance

In addition to the price disassociation from crude oil there is also another clear development visible in Figure 27 and that is the significant, and increasing, regional differences in NG pricing. The main reason for this is the shortage of the necessary infrastructure to move NG from one market to another. As previously stated LNG is the main conduit for transporting NG but since most of the available infrastructure has been purpose built for specific flows and the usage and access to the necessary land-based infrastructure is heavily regulated in some markets, it has been very difficult to redirect LNG from markets with a decreasing demand, such as North America and Europe, to markets with an increasing demand such as North East Asia, China, India and so on. This has created a situation where the NG prices have increased almost exponentially in some markets, such as Japan, when at the same time the North American market has reached historically low prices.

9.4 Price development in the future

From a shipping perspective, the key question is not what the exact price of LNG will be in the future but what the comparative price of the main alternative will be. Today HFO is the most relevant comparative fuel even if distillate fuels such as MGO and MDO will increase in importance based on present and future sulphur emission regulations in the MARPOL annex VI. Overtime the price of HFO has followed the price of crude oil in an approximate ratio of 0,7 - 0,8 (BP, 2012).

Consequently, it is useful to compare the estimated price forecasts for crude oil versus natural gas when estimating the relative development of the HUB price of LNG with the HUB price of HFO.

In a short term the most plausible development is the relative price difference between HFO and LNG will be similar to the present situation with comparatively low LNG prices in the North American market, and in principal equal prices in the European market and comparatively high prices in the Asian market.

In the long term, predictions become more difficult but some basic assumptions are still possible.

- In comparing the proven available resources of natural gas and crude oil, it is clear the future availability of natural gas looks more promising than the availability for crude oil, taking into account of present and future consumption. This should imply that the price for LNG is more appealing than the price for HFO.

- Crude oil is used as raw material for many industrial processes other than energy and heat production. These processes are, in most cases, able to pay a premium compared to energy production and it is usually not possible to substitute crude oil with natural gas. This should again imply that the price for LNG is more appealing than the price for HFO.

- Since the hydrogen/coal ratio is preferable for natural gas compared to crude oil, the contribution of greenhouse gases is reduced when burning natural gas compared to crude oil related products such as HFO. This may make LNG a more attractive fuel for many energy consumption processes in the future, which could imply the comparative price development for natural gas would be higher than for crude oil. Depending on future national and international policies regarding climate change issues, an alternate development is more plausible since any reduction of the market price of crude oil related products will probably be erased by taxation and other punitive legislation focusing on the reduction of greenhouse gas emissions.

9.5 Conclusion

The global market for LNG is undergoing rapid change, transitioning from a stable, and largely predictable, over regulated long-term market with few large players, into a more fluid, diversified and deregulated market similar to the global crude oil markets.

This change is largely due to the increasing availability of natural gas in some key markets, combined with significant changes in demand in other markets. This has resulted in a LNG and natural gas market with significant regional price variations, with market prices three to four times higher in some markets compared to others. These variations are expected to remain for quite some time due to the lack of infrastructure to move significant quantities of LNG from one market to another. Political and commercial inertia to deregulate and commercialise the markets are also contributing to the problem.

The price levels for LNG and NG in comparison with crude oil products such as traditional ship fuel seem to be favorable in the long term. This is due to higher expected consumption and increasing demand of crude-based products in other sectors other than energy and transport.

10 Cost-benefit analysis

10.1 Introduction

This cost-benefit report provides information on the expected costs for investments in, and the operation of, various types of LNG-fuelled vessels.

Comparing costs with other SECA 2015 compliance strategies, in particular the use of MGO as marine fuel, provides a useful overview for the analysis. Examples, detailing estimates of payback time, will be provided for a range of variables such as fuel price development, interest rate and so on. A number of bunkering concepts will be presented and the costs associated with the development of the necessary LNG distribution infrastructure will be illustrated for different LNG bunker demand scenarios.

10.1.1 SECA requirements 2015 and optional compliance strategies

For ship owners to comply with the upcoming environmental regulations in the SECA, three main compliance strategies have been identified based on fuel type change or the use of sulphur abatement techniques/scrubbers. Table 8 lists some fundamental aspects of the different strategies, including pros and cons from an environmental performance and economic viability perspective.

Investment costs will differ for the various strategies and are to some extent proportional to the size of the propulsion plant. A ship operator has to balance high investment costs for retrofitting new equipment or in new build projects versus long term operational costs depending on the type of fuel selected. The investment costs described in the following sections are based on the main engine power, using a “rule of thumb” for the relationship between investment and engine power (€/kW).

10.1.2 MGO

The use of MGO reduces the emission of SO_X in exhaust gases. MGO does not require extra volume for storage tanks, and retrofitting engines incurs a small, or no, investment costs. Operating costs are expected to be high due to fuel prices that many agree will to continue to rise, partly as a result of limited refinery capacity. MGO with 0,1%, or less, sulphur is readily available and has similar properties to diesel fuel used for high speed diesel engines (DMA, 2012).

To comply with NO_X regulation (Tier III), either SCR or EGR will be required. The approximate investment costs for SCR and EGR plus installation are shown in Figure 28.

	Environmental features compared to the traditional HFO alternative				Factors influencing viability compared to the traditional HFO alternative		
Alternative	**SO_X**	**NO_X**	**PM**	**CO_2**	**Cargo capacity**	**Capital Investments**	**Operating costs**
LNG	++	++	++	+	Restricted	Very high	Low
MGO	+	-	-	-	Not restricted	Low	Very high
HFO/Scrubber	+	--	+	-	Slightly restricted	High	Mediuma)

++ very good, + good. – bad, -- very bad

a) Fuel costs remain basically unchanged, a small increase (1-2%) can be expected. Cost for scrubber maintenance and waste handling are yet unknown but may add to the total operating costs.

Table 8: Comparing the alternatives; LNG, MGO and HFO (Source: DMA, 2012)

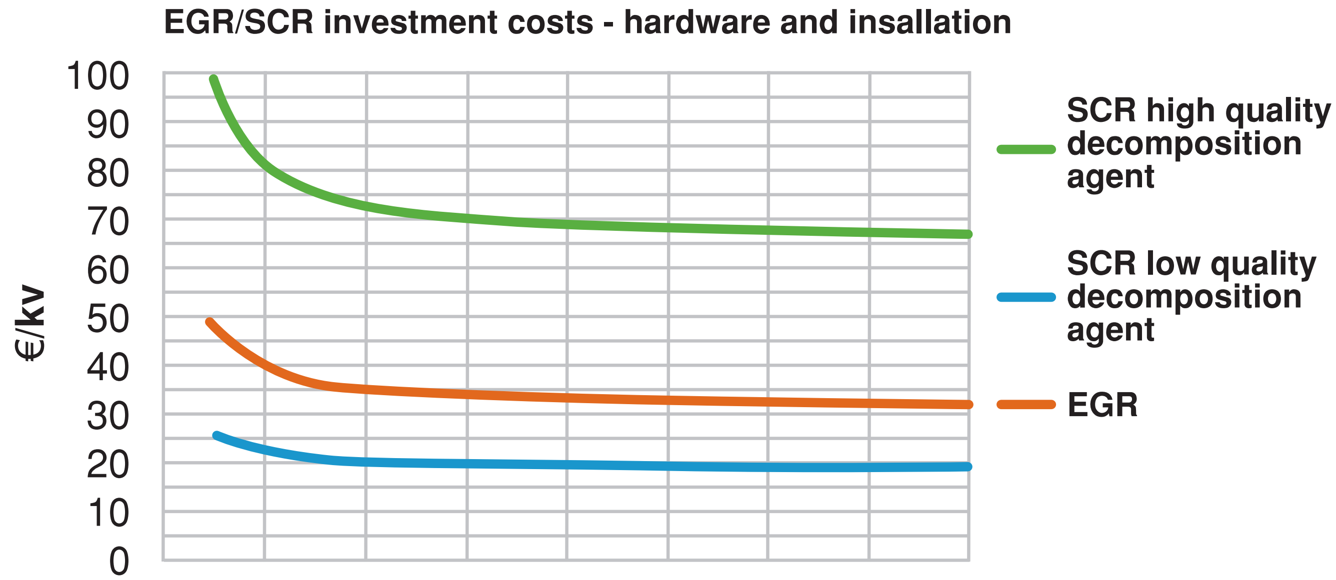


Figure 28: Investment costs for EGR and SCR with respect to hardware and installation (Source: MAN, 2011b)

Both SCR and EGR engines operating in Tier III mode will have increased fuel oil consumption. SCR engines will require an injection of a decomposition agent and special exhaust arrangements for loads below 40%. If an EGR system is to be operated on fuel with sulphur content, a NaOH solution is required in the EGR scrubber. Both engines will require power for auxiliary systems during operation (MAN, 2011).

10.1.3 Scrubber techniques

Scrubbers enable the continued use of HFO, keeping fuel costs low and avoiding the need to convert engines. It would be possible to combine with either SCR or EGR for NO_X cleaning. Wet and dry scrubbers are established techniques for land-based applications. For marine applications there are basically three different wet scrubber techniques that may be installed in ships:

- Open—Seawater is mixed with exhaust gases to dissolve the sulphur oxides
- Closed—Typically use freshwater treated with alkaline chemicals such as NaOH to achieve the same effect
- Hybrid—Use either seawater or freshwater and dry scrubbers with solid media to capture the sulphur oxides
  (USDT, 2011)

A hybrid scrubber was installed on the 21 MW diesel engines aboard the RoRo vessel Ficaria Seaways, which has been operating for about 9,000 hours since it was commissioned in May 2010 until the beginning of 2013. Note that it has been operated in closed mode for very few hours during this period of time (DME, 2011 and Marzelius, P., 2013).

Illustration: DFDS Seaways

Figure 29: Scrubber installation on Ficaria Seaways

Although it is difficult to obtain reliable cost and price informatitly with the configuration and the design of the vessel. Prices listed in the Table 9 are for guidance only.

Open scrubbers	Retrofit	New building
Cruise[4] ferry (about 40MW)	3,5 M €	3 M €
Cargo ship (about 20MW)	2,4 M €	2,1 M €
Closed scrubbers		
Cruise ferry (about 40MW)	3,4 M €	2,4 M €
Cargo ship (about 20MW)	2,4 M €	1,9 M €
Hybrid scrubbers		
Cruise ferry (about 40MW)	4,3 M €	3,8 M €
Cargo ship (about 20MW)	3 M €	2,6 M €

[3] Based on cruise ferry, but assumed applicable for a RoPax of similar power

Table 9: Indicative investment costs for different scrubbers (Source: EMSA, 2010)

Table 10 lists scrubber equipment costs for a container feeder of 2000 TEUs (USDT, 2011).

Engine size| Scrubber	Open	Closed	Hybrid	Dry
36 MW	2,4 M €	3 M €	2,8 M €	4,7 M €
16 MW	2,3 M €	2,8 M €	2,4 M €	2,5 M €
10 MW	1,4 M €	1,7 M €	1,5 M €	1,2 M €

Table 10: Scrubber equipment costs for a container feeder of 2000 TEUs

Although there is considerable variation in price estimation, the figures indicate that the cost of installing scrubbers in new build ships is less expensive. This is primarily due to the fact that retrofitting a scrubber in an older ship requires more alterations. In addition there are capital investments, increased fuel consumption related to the operation of the scrubber[5], handling waste products, and a potential reduction in cargo space due to scrubber installation to consider. Reliable scrubber availability is also important as well as the necessary port infrastructure for the efficient disposal of scrubber waste.

[5]It is commonly estimated that the operation of scrubbers gives rise to an overall increase of fuel consumption of some 1-3%.

The operating and maintenance costs for scrubbers have been estimated at 0.0025 €/kWmainh (based on energy main engine power [kW] * time at sea [hours/year]). Personnel and indirect costs are included and scaled from an assumed cost of approximately 40 000 €/year for a ship operating 6 000 hours (DMA, 2012).

10.1.4 LNG - basic engine technique, fuel tanks and bunkering solutions

Gas engines are a proven, reliable alternative but they require technical fitting and optimisation. For example, LNG storage tanks require more space than traditional fuel oil tanks, which may reduce cargo capacity depending on type of vessel, the type of fuel tank and availability of a suitable location for the LNG tanks onboard ship. Handling LNG also incurs additional costs due to the lack of existing infrastructure.

The three main LNG bunkering methods are:

- Truck-to-ship (TTS)
- Land based tank-to-ship (TPS)
- Ship-to-ship (STS)

Each bunkering method requires a different supply chain hence the varying investment costs (refer to the example in 10.3 LNG fuel supply infrastructure).

Method	Pro	Con
TTS	Limited initial costs	Limited capacity
	Use for other purposes	Impact to parallel operation
		Need quay
		Connection by road to LNG source
TPS	Variation of tank capacity	Not flexible bunkering location
	Supply by truck or ship	Space and safety requirements
STS	Flexible	Investment costs for bunker vessel
		Infrastructure investments – efficient use
		Alternative use for bunker vessel

Table 11: Pros and cons of different LNG bunkering solutions (Source: DMA, 2012)

10.1.4.1 Dual Fuel and Pure Gas

LNG may be used for engines that are able to run on either liquid fuel oils or gaseous fuel, designed as either 4-stroke or 2-stroke engines. This means different fuels can be used for propulsion depending on whether the ship is inside or outside the SECA. Relative fuel prices will determine the type of fuel used outside the SECA.

When operating on natural gas, 4-stroke engines are based on the Otto cycle, whereas the Diesel cycle is used by the engine when operating on fuel oils. The ignition source is a small amount of fuel oil which is injected and ignited by the compression heat—the burning oil ignites the gas. The 2-stroke engine combines a high pressure gas injection together with pilot diesel oil and the fuel oil ignites first—the gas is ignited in turn by the burning fuel oil. The 2-stroke engine can run on fuel oil only or on a mixture of gas and fuel oil and therefore has no, or almost no, methane slip.

Pure gas engines cannot use any kind of oil-based fuel. Most of the gas engines in use today are the

Otto/Miller type[6] with spark ignition. This technology ensures high efficiency and low emissions (DMA, 2012).

[6]A traditional Otto cycle engine uses four "strokes", of which two can be considered "high power" — the compression stroke (high power consumption) and power stroke (high power production). Much of the internal power loss of an engine is due to the energy needed to compress the charge during the compression stroke, so systems that reduce this power consumption can lead to greater efficiency.

In the Miller cycle, the intake valve is left open longer than it would be in an Otto cycle engine. In effect, the compression stroke is two discrete cycles—the initial portion when the intake valve is open and final portion when the intake valve is closed. This two-stage intake stroke creates the so called "fifth" stroke that the Miller cycle introduces.

10.2 Investment costs for LNG-fuelled ships

Different ship types have different characteristics making them more or less suitable for LNG, which in turn affects investment and operational costs. The choices for investing in LNG engines are listed in Table 12 and are based on typical ships that are considered representative of the traffic in SECA. The vessel types chosen provide a general illustration of investment costs but please bear in mind large variations exist.

The three typical vessels are a RoPax/RoRo vessel, a Coastal tanker/Chemical tanker/Bulk carrier and a container ship (700-800 TEU). These ships have different dimensions, engine power, bunkering volumes and frequency of port calls. They also have different available bunkering solutions.

These costs are rough estimates based on the main cost items to be considered for new-builds and retrofitting, with respect to machinery related costs which only constitutes roughly 30% of the total investment.

	Retrofit			New buildings		
	RoRo	Coastal tanker	Container ship	RoRo	Coastal tanker	Container ship
	2x2 700kW	8 500kW	8 000kW	2x2 700kW	8 500kW	8 000kW
Scrubber	2 300 k€	3 700 k€	3 400 k€	3 300 k€	5 100 k€	4 800 k€
MGO[7]	500 k€	700 k€	600 k€	1 600 k€	2 500 k€	2 400 k€
LNG	3 200 k€	5 100 k€	4 800 k€	4 300 k€	6 800 k€	6 400 k€

Table 12: Investment costs for retrofit installation/conversion to LNG fuel (Source: DMA, 2012)

[7]Costs for MGO alternative are mainly additional costs for NO_X cleaning equipment.

Photo: Liquiline

Liquiline semitrailer carrying a "LiquiTainer"

Retrofit	New building
Investments for gas engine	Additional investment for gas engine
LNG fuel gas supply system	LNG fuel gas supply system
LNG bunkering onboard system – space for ventilation and piping	LNG bunkering onboard system
LNG storage tanks – weight, stability, space	LNG storage tanks
Classification	Classification
Hull reinforcements?	Savings in HFO system?

Table 13: Investments needed for retrofit and new builds respectively (Source: DMA, 2012)

10.2.1 Operational costs, second hand value and other cost related aspects

The reduction in cargo space due to the extra volume required for LNG tanks can be regarded as a cost but this varies considerably for different ship types. In a GL study[8] it has been shown that due to the LNG tank dimensions, the container capacity of 1 284 TEU was reduced with 4 % (CV Neptun 1 200 design). For tanker vessels, however, it may be possible to locate the LNG fuel tanks on deck, as with the first retrofit, the Bit Viking, where two 500 m^3 LNG fuel tanks are located on deck.

The LNG FOB price is a result of the LNG hub price together with costs for LNG fuel supply chain investments and operations, divided per tonne LNG. The operational costs are harder to estimate since they vary considerably from case to case depending on ship type, and where bunkering is undertaken.

10.3 LNG fuel supply infrastructure

To illustrate different costs for shipping segments with respect to LNG bunkering, two scenarios based on a container feeder are provided. In the first scenario the container feeder uses an STS bunkering method.

Photo: Liquiline

”LiquiTainer” on ship

	Container feeder[9]	
Scope	Container feeder engaged in 7-days routes between St- Petersburg, Stockholm, Malmö-Copenhagen and Gothenburg.	
Ship size	9 000 dtw, 800 TEU	
Fuel consumption	12,3 tonnes LNG/day. Operating on average 12 h/day with 18 knots is 6,2 tonnes /day[10]	
Route	Total travelled distance 3 000 nautical miles per route	
Number of vessels	10 in 2015, 30 in 2025	
Bunkering method	STS, available bunkering time 6-12 hours	
LNG demand	4 500 tonnes LNG/year in 2015, 13 500 tonnes LNG/year in 2025	
	LNG fuel supply chain fuel supply chain	
LNG source ROTTERDAM	295 €/tonnes	LNG price in Europe
Transport to GBG	39 €/tonnes	Additional cost for transportation[10]
Storage in GBG	39 €/tonnes	Additional cost for storage
LNG Source GBG	373 €/tonnes	LNG price in Gothenburg
LNG Bunker vessel	225 €/tonnes	Costs for a small bunker vessel (~70 tonnes) is approximately 14 000€/day
FOB	493 €/tonnes	LNG SourceGBG+LNG Bunker vessel * Net calorific value for HFO (82% of LNG) (IMO, 2012)
FOB MGO	762 €/tonnes	Comparative FOB price for MGO in Gothenburg

[8] IMO Caribbean, 2012
[9] The example of container feeder, ship size, FOC and LNG demand are referenced to DMA, 2012.
[10] Based on a 5 000 tonnes LNG feeder en route Rotterdam-Gothenburg, 31 000 €/day (IMO, 2012).

Table 14: FOB cost of LNG delivered STS

In the second scenario the same container feeder uses a TTS bunkering method, which has an impact on the LNG supply chain and the FOB price.

	LNG fuel supply chain	
LNG SourceGBG	373 €/tonnes	LNG price in Gothenburg
LNG Tank truck	13 €/tonnes	Three trucks active in Gothenburg can supply the 10 container feeders
FOB	316 €/tonnes	LNG SourceGBG+LNG Tank truck * Net calorific value for HFO is 82% of LNG (IMO, 2012)
FOB MGO	762 €/tonnes	Comparative FOB price for MGO in Gothenburg

Table 15: FOB Cost of LNG delivered TTS

11 Knowledge, training and certification

The on-going paradigm shift from oil to LNG as marine fuel is a technical, environmental and regulatory shift. It also implies a significant change in the knowledge and training required by the various professionals who deal with shipping on a regular basis. The following chapter identifies several different groups of professionals who will be affected by these changes and also provides some indication of the current levels of general knowledge and awareness of the implications of using LNG as marine fuel among these groups. It will also provide some recommendations for the project stakeholders as to what action will be required to secure the availability of professionals with the appropriate knowledge to meet the future demands.

11.1 Crew on IGF vessels

11.1.1 Existing regulatory framework

The main regulatory body for all commercial vessels in international trade is the IMO, a member organisation and a part of the UN. Today the IMO has 170 member states and three Associate Members. There are also a number of IGOs and NGOs that have cooperative or consultative status in relation to the IMO.

The IMO regulates international shipping activities through a number of conventions. These conventions are not laws as the IMO has no authority to enforce them. Instead it is up to each member state to apply the conventions within the context of each national regulatory framework. When a new or revised version of a convention is published, a formal approval process is initiated among the member states. This process will vary depending on the extent of the change but in principle each member state that accepts or approves a new or changed convention has to adopt it as part of their national legal system. This must be in line with a number of conditions specified in the basic framework of rules and regulations of IMO membership. Further information about how the IMO regulates international shipping is available on the IMO webpage.

When it comes to the regulations governing the education and training for the crew of commercial vessels involved in international trade, the main IMO convention is the STCW convention. The latest version of this convention, the 2011 edition, included no rules or regulations concerning educational standards for the crew onboard IGF vessels. The main responsibility for the development of the STCW convention is the IMO sub-committee STW.

In Chapter 8 of IMO Resolution MSC.285(86) some basic operational and training requirements are specified. As with the rest of the resolution, MSC.285(86) is based on work undertaken by the Norwegian authorities since the late 20th century, and has been developed into an IMO resolution by the IMO BLG sub-committee.

11.1.2 Common Practice

Since the IMO Resolution MSC285(86) is non-compulsory and there are no rules or regulations stated in the present STCW convention, it is up to each member state to decide on the educational and training standards for crew operating vessels flying its flag. Up until now all member states that operate IGF vessels have used the requirements in the interim guidelines as a starting point, and the further requirements for education and training are usually developed for specific vessels on a case-by-case basis. In the absence a more general and internationally adopted set of rules and regulations, this ad-hoc approach to education and training will probably persist in the near future too.

11.1.3 On-going activities

At the last meeting of STW, STW43 held in late April 2012, the topic of regulation for education and training for IGF vessels was addressed by BLG as a result of BLG16 in relation to the development of the IGF code as described in section 5.1.5. In principal STW43 appreciated the topic raised by the BLG16 but due to the fact that the topic was sent to the STW shortly before the STW43 meeting, STW43 didn’t take any immediate action during the meeting since the topic wasn't properly prepared. Instead STW43 invited Member Governments of the STW to consider the matter in detail and submit comments and proposals to STW44, planned for 13-17 May 2013.

Within the LNG ship fuel advisory group, described in section 5.3.2, work has begun to develop training requirements for IGF vessels and the group aims to have something ready to STW44. The development is led by Warsash Maritime Academy in Southampton, UK.

11.1.4 Recommendations

A number of different studies that have been performed in relation to the development of LNG as marine fuel, such as the LNG northern Europe Infrastructure project, have identified training for crew has as one of the main areas that requires development. Safety concerns and the risk of developing a shortfall in suitably trained crew were cited as the main reasons.

Since shipping is a truly international business, it is important that all initiatives seeking to address education and training needs work to produce a common international standard for training of IGF crews. The best forum to do this is the STW committee within the IMO, and member state authorities, NGO s and other relevant stakeholders are encouraged to focus its efforts on getting the necessary requirements into the next amendment of the STCW convention.

11.2 Bunker vessels crew

11.2.1 Exiting regulatory framework

In contrast to IGF vessels there is already a valid international regulatory framework for the required training and certification of crew working on LNG bunker vessels in the STCW convention, with the main demands are defined in Regulation V/1-2. All member states that have ratified the STCW convention are obliged to follow the minimum standard of competence as defined in the convention. However, any member state may impose higher standards than defined in the STCW convention if required.

In principle there are two types of certificates—general and special. The general certificates are related to the vessel itself and have nothing to do with what the type of cargo handled. Special certificates are specifically for the type of cargo handled, and generally apply to tankers as well as passenger vessels.

To serve in any position with specific assigned duties and responsibilities related to cargo, or cargo equipment, on an LNG bunker vessel, crew must hold a special certificate in basic training for liquefied gas tanker cargo operations in addition to the basic certification of the position held onboard. To qualify for this certificate, crew members need at least three months of approved seagoing time as well as the participation in a basic training course approved by a member state.

To serve in any position with immediate responsibility in relation to cargo and cargo handling, crew must hold a special certificate in advanced training. In addition to the requirements related to the basic training, crew must have either at least three months of approved seagoing service time on a liquefied gas tanker, or one month in a supernumerary capacity including not less than three loading and three discharging operations. Crew are also required to participate in an advanced training course approved by a member state. Note that all crew must hold a basic training certificate before they are allowed to begin the training or seagoing time for the advanced certificate.

11.2.2 Availability

If the demand for LNG as a general marine fuel grows rapidly, the demand for LNG bunker vessels also will grow in the same pace. If bunker vessel operators are going to meet these demands, they will require certified crew members.

Section 11.2.1 outlined the basic steps to acquire the necessary certificates to serve in any position onboard an LNG bunker vessel. It will be necessary for senior officers to complete four to six months of approved seagoing time to qualify for the advanced certificate, and a minimum of three months of approved seagoing time for all crew assigned any kind of duty related to cargo handling and cargo equipment.

Since the global numbers of liquefied gas tankers are currently limited, the numbers of seafarers with the required certificates are also limited. The number of training positions onboard these vessels is also restricted since each vessel can only accommodate a few extra crew members. This implies that based on present regulations, it will be difficult to react quickly to the changing demands for an increased number of certified seafarers for the LNG marine fuel market.

11.2.3 Recommendation

If the LNG marine fuel market takes off, there is a significant risk of a shortage of certified seafarers for LNG bunker vessels. Member state authorities, NGO's, ship operators, educational institutions and other relevant stakeholders must address this potential problem. One option may be to develop alternative solutions to meet the demands for approved seagoing time as stated in the STCW convention.

11.3 Inland water way shipping

Sections 11.1 and 11.2 only covered vessels that are designed and operated for international coastal and open sea trade in line with the IMO regulation. In addition to these types of vessels, several countries around the North Sea apply adopt a different set of rules and regulations for inland waterway vessels. The basic regulatory framework for these vessels is described in section 5.5.

Historically the standards for training and certification for the crew operating an IWS vessel have been lower compared to the standards for vessels involved seagoing trade, despite the fact that the STCW convention was used as a starting point for the development of IWS rules. Recently the trend has been towards developing a regulatory framework for training and certification of crew on IWS vessels that complies with the STCW convention. This is particularly the case for vessels transporting various types of dangerous goods.

11.3.1 Gas-fuelled vessels

At present there are no general regulations covering gas-fuelled inland waterway vessels and it is up to each member state to determine the necessary training and education requirements for the crew serving on these vessels. At present there is only one gas-fuelled vessel, MTS Argonon, operated under the inland waterway vessel regulation in Europe. MTS Argonon is a 6 100 dwt bunker ship serving the port of Rotterdam and as such she must comply with the RVIR, ADN as well as EU directive 2006/87/EC. Since there are several parts of these regulations that she doesn't meet, the authorities in the Netherlands received special authorization from both the UNECE and the CCNR. The authorisation included some minor information about training, including the following:

Training

The ship's crew will be trained on the use of LNG. This is one of the basic assumptions of the HAZID study. The training will cover the hazards of LNG, the bunkering procedures, and the measures to be taken in the event of an emergency. The suppliers of the engines, cryogenic storage tank and the LNG system are expected to contribute to this training. The requirement to complete this training will be included in the ship's safety manual.

Photo: Deen Shipping

Figure 30: MTS Argonon - an LNG-fuelled bunker vessel

11.3.2 Bunker vessel crew

Many of the bunker vessels in use today in the main ports of Northern Europe are IWS vessels. It is likely that many of the LNG bunker vessels will also be IWS vessels. In the ADN rules there are some general requirements concerning the training and education of the crew of IWS vessels transporting dangerous goods, but since at present LNG isn't allowed to be transported by IWS vessels, there are no special recommendations for LNG.

11.3.3 Recommendation

To promote safe and efficient operation for both gas-fuelled vessels as well as IWS bunker vessels, it is important to address the general training and education requirements for the crew of these vessels. The most efficient and effective way to do this is probably to follow the development of seagoing vessels and adapt the regulations for IWS vessels. Such an approach should ensure a stringent, as well as appropriate, regulatory framework.

11.4 Shore based LNG supply professionals

There are many rules and regulations and a number of guidelines regulating the operation of onshore LNG activities such as terminal operation and LNG truck operations. The main regulations, described in section Feil! Fant ikke referansekilden., include requirements and recommendation concerning training and education. In addition to this it is essential that professionals involved in LNG bunkering operations have sufficient knowledge of the bunkering process itself.

11.5 Directly related professionals

There are several groups of professionals that will be directly affected by the introduction of LNG marine fuel. This will primarily include professionals who already involved with ship and shipping activity and includes:

Photo: Liquiline

Liquiline - LNG emergency exercise

- Yard and service staff
- Fire and emergency services
- SAR staff
- Port operators
- Pilots
- Tug operators

11.5.1 Demand

The demand for knowledge will vary between these groups but all will require additional knowledge to be able to perform their normal activities. The future demand will be based on commercial, safety and security considerations. For example, an engine repair man working in a yard will require additional training on gas-fuelled engines and gas fuel systems to be able to perform his job both effectively and safely. Failure to acquire and maintain the necessary skills could result in redundancy, for both the employee and the employer, if they cannot provide the necessary expertise.

The same will apply to Fire and Emergency Response and SAR staff who must understand the differences between a traditional oil-fuelled vessel and an LNG-fuelled vessel in an emergency situation. They must also understand how to handle these vessels in many different situations. If emergency response staff do not possess the necessary skills to deal with the situation facing them, there is a significant risk that a small emergency situation may develop into something much more serious.

11.5.2 On-going activities

Until now most activities related to the demand for training have been linked to specific projects with little development of a more holistic approach to training and education.

Recently there have been a number of initiatives that have at least attempted to address the demands for education and training related to the development of LNG marine fuel.

A joint committee has been established with participants from a number of authorities in the Nordic countries, including both maritime and shore-related authorities. The purpose of the committee is to share knowledge and experience, align the development of LNG marine fuel by the authorities in the different countries and to promote Knowledge, Training and Certification.

11.5.3 Recommendations

If the LNG marine fuel market is successful, it will be important for several professional groups to acquire the necessary additional knowledge and training. For some stakeholders the inability to meet these requirements may impose commercial risks for individuals, companies and industries and for others the lack of proper knowledge and education may result in a significant risk to individuals and society as a whole.

To meet this future demand of knowledge and training cooperation between the different stakeholders such as LNG suppliers, authorities, educational institutions as well as the different professional groups is essential. The objective is to identify the demand and to develop solutions to meet that demand.

11.6 Authorities

11.6.1 Demand

In addition to maritime authorities and other shipping related authorities, there are a number of other authorities that will be affected by the introduction of LNG marine fuel. The different properties of LNG compared to the fuel oil used at present must be understood by all the relevant authorities such as local planning and building departments, environmental departments and authorities and so on. Without this understanding, there is a significant risk that ignorance may hinder or restrict development of the LNG marine fuel market, or result in situations that may introduce additional and unacceptable risks for third parties.

11.6.2 Recommendations

It is recommended that the stakeholders address the demand for additional education and training for all relevant civil servants to develop a common understanding of both the possibilities and problems associated with introducing LNG as marine fuel.

12 Brunsbüttel – Establishing an LNG terminal for the North and Baltic Sea areas

12.1 Project background

Brunsbüttel Ports GmbH and Gasnor AS have agreed to start the process for establishing the first LNG bunkering facility in central Europe. With this important step they are leading the way in adopting LNG as marine fuel in the ECA area. This initiative is a major showcase for the CNSS project and will provide a practical example of risk and cost analysis required in similar potential infrastructure projects in the North and Baltic Seas.

The city and the ports of Brunsbüttel are located at the lower Elbe and at the Kiel-Canal. There is three ports around the city of Brunsbüttel—the Elbehafen, the Oilport and Port of Ostermoor. These ports offer direct access to the North and Baltic Seas, and proximity to Hamburg provides access to nearby industrial areas and the European inland waterways. The location of the three different ports is given in Figure 31.

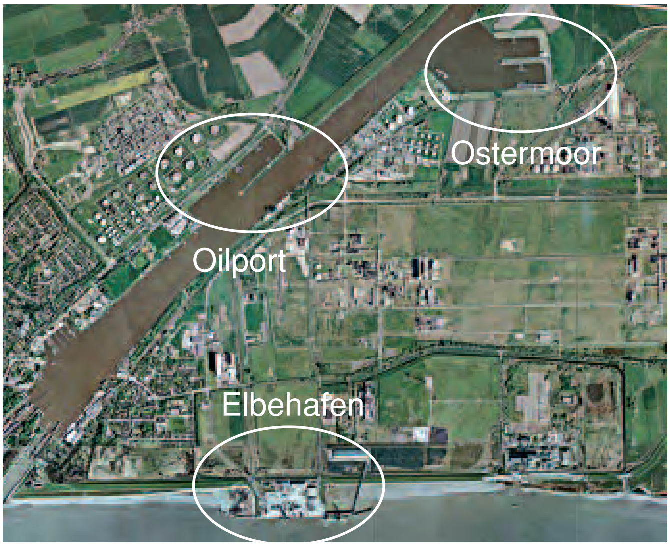


Photo: Google Map

Figure 31: Groups of ports in Brunsbüttel

The Oilport is located at the southern end of the Kiel-Canal, near the Brunsbüttel locks. This port handles various liquid products and consists of five quays for the mooring of vessels and barges, of which four are operated by Shell Deutschland GmbH. The maximum draught in the port is 10.4 meters, which allows both inland and seagoing vessels to moor.

The port of Ostermoor is located at the southern end of the Kiel-Canal, also close to the Brunsbüttel locks. The port was erected in 1975 as a supply and disposal facility for nearby industry (Bayer AG Werk Brunsbüttel / TOTAL Bitumen Deutschland GmbH / Yara Brunsbüttel GmbH). The port has six quays for handling various products, like ammonia, urea, crude oil and various liquid chemicals.

The Elbehafen Brunsbüttel port is located along the Elbe River. The Elbehafen is a multipurpose port where bulk goods (LPG and oil), heavy gear, containers and general cargo can be handled. The port supports a variety of transport options including truck, rail, feeder, sea vessels and barges and has six quays for the mooring of vessels and barges. The maximum draught in the port is 14.4 meters.

12.2 Abstract

Planning and building an LNG bunkering facility is complex. It requires systematic analysis and risk assessment scenarios similar to that undertaken for aircraft collisions, terrorism, industrial and natural disasters. At the same time it is also important to consider the risk posed by the terminal to the surrounding areas. However, it is difficult to assess the scale of the damage before the actual flows and specific characteristics of the bunkering facility are known. A case by case approach is therefore required to understand the specific risk and conditions at specific locations.

At present there are no general requirements in the EC for establishing an LNG infrastructure to supply ships with LNG fuel. If this market is to grow in Europe in the years to come, it would be beneficial to establish systems and requirements that are understood and reliable.

This report discusses one approach to assessing a potential bunkering facility. Based on this showcase example, the LNG supply chain has an important role to play in minimising costs. Optimal solutions for bringing the LNG to market are crucial in this respect.

12.3 LNG supply chain

12.3.1 LNG transportation

LNG can be transported either by ship or by truck. By truck it can be transported in a container solution or on a trailer. The container could also be transported by a container feeder or by railroad. Transporting LNG by rail is not currently undertaken in any part of Northern Europe. By container, the transportation from production to customer can become more complex, involving a number of supply chain participants. The ideal transport solution is closely related to the customer flow and the size of the handling terminal.

12.3.2 LNG transportation by ship

Most LNG is transported by large ships. At present there are over 360 LNG tankers in operation (http://www.giignl.org/). The largest ship has a loading capacity of 266 000m3 of LNG, and the smallest one has a capacity of 1 100m3. The choice of tanker for the LNG supply chain depends on the size of the terminal, and the method of transportation is always based on optimal cost. For example, using a large scale LNG carrier to deliver to a small scale LNG terminal is not cost efficient. To make the most efficient use of large ships, combination voyages, where ships can discharge at more than one terminal, are the best option.

There are currently three ships operating in Europe that would be appropriate for supplying small scale LNG terminals. There are however, some small LNG tankers under construction for operation in Europe.

Photo: Harald Arnøy

Figure 32: Pioneer Knutsen

The smallest LNG carrier in the world is the 1 100m3 Pioneer Knutsen (Figure 32). Built in 2003, it is owned by Knutsen OAS Shipping AS and operates under a long term charter to Gasnor AS. It is used for loading LNG at the Kollsnes LNG plant for delivery to small LNG terminals in Norway. As of 2013, around 13 terminals can receive shipments from the Pioneer Knutsen.

The second ship is the 7 500m3 Coral Methane operated by Anthony Veder (Figure 33), also under a long term charter to Gasnor AS. It is a typical combined gas carrier with the capability of carrying

Photo: Antony Veder

Figure 33: Coral Methane

ethylene, propylene, LPG and LNG and at present delivers to eight terminals. The third and fourth vessel is operating for other distributors of LNG in Scandinavian.

There are several combined gas carriers under construction. Ship owner Norgas have a series of six 10 000m3 and 12 000m3 gas carriers under operation in the Far East. Anthony Veder has three vessels under operation included Coral Methane.

The Anthony Veder and Norgas ships will all be suitable for transporting and supplying small scale LNG terminals in Europe and Brunsbüttel, although they will have larger cargo capacities than are likely to be required for the LNG terminal in Brunsbüttel.

Making the most efficient use of these ships therefore depends on an optimal combination of voyages within a limited area where the ships can discharge at several terminals.

12.3.3 LNG transportation by truck

At present there are two types of LNG trucks in operation throughout Europe. The loading capacity is between 50 to 80m^3 of LNG. The transported amount of LNG depends on the axle load, the maximum load, and the length of the vehicle permitted in the country through which the LNG is transported. In Germany the maximum weight for a truck with a trailer is 40 tonnes. This means that the maximum load of LNG is approximately 18 tonnes, or 42-45m^3 depending on the gas specification.

The LNG tanker trucks in Figure 34 can carry 55m^3 of LNG. They are widely used within the Norwegian and Swedish LNG supply system. Although trucking is a reliable and flexible transportation option LNG, it is less cost effective than ship transportation if the volumes of LNG are sufficiently large for a sustained period. The optimal transport distance via truck is up to 600km approximately.

Photo: Stein Petter Eriksen

Figure 34: LNG truck

12.3.4 LNG transportation using container solution

The transportation of LNG can also be based on a container solution, using a standard 40-foot ISO container fitted to standard trucks and trailers. The container can be transported from a production plant or an export facility to its final destination via rail or container vessels. At Brunsbüttel it could be possible to receive containers directly from container vessels in the port. It is also possible to receive containers from trains near the port, a solution which would also involve trucking the LNG from the train station to the port.

The maximum container weight in Germany is 44 tonnes, for a three-axle motor vehicle with a two or three-axle semi-trailer carrying a 40-foot ISO container as a combined transport operation.

A container solution is probably not an efficient solution for larger volumes of LNG, and longer transport distances. In Europe there is limited experience with the container solution as a part of the logistical LNG chain.

Photo: Chart Ferox a.s

Figure 35: LNG container

12.3.5 Transport solution for Brunsbüttel

In this showcase project it is assumed that the LNG tanker CNSS tanker will undertake the transportation from the LNG import terminal to Brunsbüttel. The transport time is 10 hours. The loading and discharging of the ship is assumed to take 22 hours.

12.4 Alternative terminal concepts

Today there are two main types of tanks in use as bunkering terminals—pressurized and atmospheric tanks. The atmospherics tanks will be either steel or concrete tanks.

When planning an LNG supply system, it is very important to consider the type and size of the terminal. The number and frequency of bunkering operation is also of great importance. At the same time, the logistical system for supplying the terminal is crucial in optimizing the whole supply chain.

Several ISO technical committees are developing standards and specification for LNG installations and equipments. The ISO/TC 67 - Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries, is one such example (www.iso.org). In Europe the ISO standards are implemented by all European member states as EN-ISO standards. A European standard has also been developed, CEN/TC 282. For further information please refer to LNG LESAS Project – Final Report WP3.

12.4.1 Atmospheric tanks

Atmospheric tanks are designed to hold the LNG below boiling point and under 0,1 bar pressure. Atmospheric tanks are usually constructed on site, and cannot be moved to other locations unless the tank is stripped down. As a general rule, atmospheric tanks tend to be larger than pressurized tanks. To be able to handle the boil-off from atmospheric tanks, the tank facility must be connected to local gas grid, or there a reliquefaction unit must be installed to keep the gas below boiling point. The operating volume of the tanks is usually less than the gross volume of the tanks. Under normal operation the net operating volume is approximately 90%. The boil-off gas rate is normally around 0,2% per day (MAGALOG, 2008)

Atmospheric LNG tanks can be divided into:

- Single containment type
- Double containment tank
- Full containment tank
- Membrane containment tank

The atmospheric tank is constructed from concrete or/and stainless steel.

12.4.1.1 Steel tanks

Steel tanks are constructed on site, and cannot be moved to other locations unless the tank is stripped down. Steel tanks are probably most effective in a mid scale range (see Figure 36). As the tank cannot handle any pressure, it is important that the boil-off gas is used locally.

Photo: Gasnor AS

Figure 36: Steel tanks at Kollsnes

12.4.1.2 Concrete tanks

Concrete tanks are usually built for large scale operations. One of the smallest concrete LNG tanks was built in Sweden (see Figure 37). The capacity of the terminal is 20 000m^3.

Photo: AGA AB

Figure 37: AGA LNG terminal Nynäshamn, with Coral Methane

So far there is just one concrete tank used for LNG bunkering anywhere in the world. This tank is located outside Stavanger in Norway, and has a capacity of 30 000m^3. This tank is connected to an LNG train and the local gas grid, and it is also the tank used to load LNG tankers.

12.4.2 Pressurized tanks

Pressurised tanks are designed to hold a few bars of pressure. They are cylindrical steel structures, mounted either horizontally or vertically, and pre-fabricated before shipment to the point of installation. Pressurised LNG tanks have been installed in Norway with volumes ranging from 20m^3 to 1 000m^3. These tanks are best suited to relatively small storage volumes and several tanks may be installed together. A tank farm can be increased or reduced in size by adding or removing tanks according to supply demand. The largest pressurized tank farm in Norway has a capacity of five 900m^3 tanks. Pressurized tanks or tank farms do not need to be connected to a local gas grid, although this provides some security against flaring. Setting up a large tank farm requires a lot of space. If the capacity required is over 10 000m^3, it is generally assumed that an atmospheric tank is preferred. The boil-off rate is normally 0,01 - 0,03% per day (Nils Jarle Lindtner, Gasnor).

Photo: Gasnor AS

Figure 38: Pressurized tanks

12.4.3 New and developing concepts for LNG terminals

There are many LNG tank designs under development at present. The main motivation for a new design is for use onboard ships, to reduce costs and weight. Another important consideration is to be able to fit the tanks into void spaces onboard ships. These new designs include, for example, composite techniques and combination of pressurized and atmospheric tanks (www.forskningsradet.no/servlet/Satellite?c=Prosjekt&cid=1253966888981&pagename=maroff/Hovedsidemal&p=1228296528829).

New land-based tanks are also being developed. The new designs include the use of other metals and non-cylindrical shapes. The main motivation in this case is lower investment cost.

12.4.4 Terminal in Brunsbüttel, concept for show case

In this showcase example it is assumed that the bunkering terminal in Brunsbüttel will consist of a pressurized 5X1000m^3 tank farm.

12.5 Potential market for LNG as fuel in the showcase

Brunsbüttel is located at the end of the Elbe River. The Elbe is the highway to the Port of Hamburg, approximately 40 nm from the coast. Hamburg is one of Europe's largest ports.

The port is at the start of the Nord-Ostsee Kanal or Kiel Canal (nearly 53 nm in length) and saves on average 250 nm of sailing distance by diverting traffic to the Baltic Sea instead of sailing around Denmark.

12.5.1 Shipping traffic from the Kiel Canal to Baltic Sea area

According to the Kiel Canal web page, the shipping traffic through the canal in 2010 and 2011 was

31 933 and 33 522 ships respectively (www.kiel-canal.de).

Type of ship	
General cargo (including dry bulk)	45 %
Container ships	16 %
Oil tankers	15 %
Non cargo ships (for example, fishing, naval or service ships)	10 %

Table 16: Ship type in Kiel Canal

By using the Kiel Canal shipping traffic can save 335nm sailing from Hamburg to Stockholm, or 105nm sailing from Antwerp to Copenhagen.

12.5.2 Shipping traffic from the Elbe to Hamburg

The Port of Hamburg is one of the largest ports in Europe after the Port of Rotterdam and is often referred to as the gateway to the world. Shipping lines connect the port to more than 900 other ports in 174 countries around the world. There are nearly 50 feeder services covering the North and the Baltic Seas.

According to the Port of Hamburg's home site, a total of 9843 ships called at the port in 2010. The largest group of ships in 2010 are listed in Table 17 (http://www.hafen-hamburg.de/en).

Type of ship	Numbers in 2010
Container	5 252
Bulk	1 563
Multipurpose vessel	979
Tanker	1 339

Table 17: Number of vessels in the Port of Hamburg

12.5.3 Potential market in the show case

The environmental regulations governing the operation of ships the North and Baltic Seas will force the shipping industry to rethink. The ECA requirements regarding sulphur content in fuel and NO_X emissions will mean the shipping industry must use cleaner fuel or to start using exhaust cleaning systems. Already today the requirements for sulphur content in EU ports is below 0,1 percent. From 2015 existing ships in the ECA area must use the same type of fuel or they must install scrubbers to remove the sulphur and particulate matter from the exhaust.

12.5.4 Identify the client base and the type of shipping

Shipping can be divided into six types:

- Tank
- Bulk
- Container
- Passenger
- Vehicle
- Other

At present it is mainly passenger and other ships, for example Platform Supply Vessels (PSV), that are using LNG as marine fuel. As of 2012 there are 25 such ships in operation using LNG as fuel. So far there is just one tanker (in addition to the small LNG tankers) using LNG as fuel. This is the Swedish costal tanker Bit Viking owned by Tarbit Shipping AB, operates under time charter for Statoil ASA. Bit Viking has been retrofitted for LNG propulsion, a conversion that was in part financed by the Norwegian NO_X fund.

Photo: Tarbit Shipping AB

Figure 39: Bit Viking

There are approximately 35 new LNG ships under construction (http://blogs.dnv.com/lng/). Large passenger ships like Viking Line and Fjord Line will represent a new market for LNG-propelled ships. In the US and Canada passenger ferries are to be retrofitted for LNG propulsion, making them the first passenger ships using LNG in North America. At the same time at least two PSV's will be in operation by 2015 in the Gulf of Mexico. The world's first tugs with LNG propulsion will be in operation from 2014 at Kårstø, and at least three bulk carriers will be in operation by 2013 in the ECA area.

In 2013 there will be around 50 ships worldwide using LNG. Depending on the economic situation, the number of ships using LNG is likely to increase dramatically over the next 10 years. It is expected that new build ships become the largest group of LNG-propelled ships, but retrofitting will also become more of an option for certain types of ships. According to the North European LNG Infrastructure Project the annual LNG fuel consumption in the SECA area will be more than 17 million tonnes in 2030 (DMA, 2012).

12.5.4.1 Triggering the client base

According to the MAGALOG report, the following fuel requirements, per ship per week, can be expected:

Ship type[11]	kW engine	m^3 LNG pr week	Annual fuel requirements, in tonne
Bulk, RoRo	12 000	400	6 700
Bulk, RoPax	20 000	700	15 400
Passenger	15 000	750	16 000

Table 18: Ship type and fuel requirements

If it is assumed that 2-5% of the total annual fuel requirements in the SECA area will be LNG by 2020, then there will be at least 250 LNG-propelled ships by 2020, based on average ship requirements.

[11]ASSUMPTIONS: Average 75% of time spent at sea; 85% average engine utilisation. kW engine sizes are close to averages for existing vessels in the Baltic and North Seas. 50 weeks/year. 1 m^3 of LNG corresponds to 0,44 tonnes.

According to Lloyd's Register the number of LNG-propelled ships will depend on the pricing of LNG. A price drop of 25% compared to current market price will result in nearly 2,000 new build LNG ships by 2025. The Lloyd's Register study predicted 650 vessels worldwide in 2025, consuming 24 million tonnes of LNG (Lloyd's Register, 2012).

12.6 Preparations for the application

12.6.1 General situation

At present there is no existing LNG bunkering terminal in Germany. In accordance with EC requirements an application to develop such as terminal must at least fulfil Directive 2001/42 - Strategic Environmental Assessment (SEA), Directive 85/337 – Environmental Impact Assessment (EIA), Directive 92/43 Natura 2000, Water Framework Directive 2000/60, and DIRECTIVE 2009/147/EC.

In addition, the local area is subject to German national legislation and local restrictions. For example, preliminary examination of an environmental compatibility assessment (screening) is required under German legislation. Additional reports related to noise, emissions, fire protection, explosion protection and so on, may also be requested as part of the final application.

Therefore the amount, type, location, arrangement of tanks as well as the number of ships, for LNG supply, bunkering and transportation by trucks during the various phases, must be identified in the final application. A highly specialised report like this must be undertaken by certified professionals, with the necessary skills and relevant experience endorsed by the stakeholder authorities.

At present the application process is complex and unpredictable. It is hoped that the process will become a more transparent in the future.

For a more detailed study see The North European LNG Infrastructure Project (DMA, 2012).

12.7 Evaluation of bunkering procedures

12.7.1 Type of bunkering

As of 2012 there are no standard operating procedures for bunkering LNG. The requirements vary from place to place. There are, however, recommended standards for ship-to-ship transfers that have been developed by SIGGTO (Society of International Gas Tanker and Terminal Operators Ltd). SMTF (Swedish Marine Technical Forum) together with FKAB Marin Design, Linde Cryo AB, DnV, LNG GOT and White Smoke AB, has developed a procedure for LNG bunkering using flexible hoses. For more information see: LNG ship to ship bunkering procedures

Bunkering can be done directly from the truck or from the terminal. It is also possible to bunker directly from a small LNG tanker or a similar bunker barge. Bunkering is usually undertaken today either from truck or from onshore bunkering terminals. Gasnor has developed bunkering procedures for bunkering operations STS between the Pioneer Knutsen and the costal tanker Bit Viking.

As of 2011 Gasnor AS has completed over 52 000 LNG transfers without incident.

12.7.1.1 Truck

Of the 16 coastal ferries currently running on LNG in Norway (2012), 12 are regularly fuelled from tanker trucks parked alongside the vessel, which can deliver $55m^3$ of LNG. Bunkering usually takes place at night when the ferries are out of service. The loading operation to pump LNG from the tanker usually takes 1 ½ hours to complete.

Bunkering from a tanker truck takes longer than other alternatives due to the limited pumping capacity. Larger pumps will restrict LNG capacity due to weight restrictions. However, bunkering from a truck has the advantage of flexibility. The tanker truck can be parked on the jetty next to the ship, connected via a flexible hose, and be shielded from other operations while bunkering is ongoing.

12.7.1.2 Terminal or fixed lines

Today bunkering from a fixed line or an onshore terminal occurs at four locations places in Europe, including Saga Fjordbase in Florø, Costal Central Base at Aagotnes, and at Vestbase in Kristiansund with six supply ships. Four ferries bunker from the terminal at Halhjem, and Bit Viking bunkers from a terminal outside Stavanger. The bunkering capacity is around 100 - $150m^3$ per hour, and the bunkering equipment (the pumps and pipes) can be easily reconfigured to accommodate different capacities. This solution is quick and reliable. The vessels will always be able to bunker the volume of LNG that is required.

A fixed bunkering line needs a certain amount of dedicated space for the installation of a permanent LNG tank within a short distance to the quay.

Photo: Gasnor AS

Figure 40: Halhjem LNG terminal

12.7.1.3 Bunker barge

Traditional bunker fuels are usually delivered to ships from a barge, which may be a self-propelled ship or a barge dependent on a tug. LNG bunkering from a barge may provide more efficient bunkering of vessels at different locations around a harbour area. If the ship is moored alongside, the bunkering operation will be carried out from the other side of the ship. Bunkering from a barge is a flexible and efficient solution for larger volumes of LNG, delivered to several ships located throughout the harbour.

Although several studies have been commissioned by ports considering LNG availability, there are no LNG bunkering barges currently in operation as of 2012. However, it is anticipated that a bunker barge, a reconditioned double-ended costal ferry, will be brought into operation in Stockholm in 2013.

12.7.1.4 Assumed bunkering solution in Brunsbüttel

In this showcase project the bunkering will take place from a LNG terminal, via pipeline and flexible hoses/bunkering arms (Figure 41).

Photo: Gasnor AS

Figure 41: Fixed bunkering lines

12.7.2 Perform preliminary hazard analysis of bunkering, in and out of the terminal

To perform a safety review for the chosen location, one of the steps is complete a HAZID study. The purpose of a HAZID is to identify possible risks at the terminal by analyzing all installations close to the terminal and bunkering area and all operations within the terminal and bunkering area.

HAZID is a well-established, systematic technique for identifying hazards and is the accepted procedure for identifying and avoiding, or mitigating, any potential impact. Hazard identification is an important step in risk assessment and risk management. For example, refer to LNG bunkering, a safety issue from Germanischer Lloyd for a model used in Hamburg.

12.8 Risk and Safety screening in Brunsbüttel

12.8.1 Safety screening analyzes

It is assumed that an LNG bunkering terminal in Port of Brunsbüttel will be developed within the blue circle identified in Figure 42. It is important to keep the distance from the jetty to the terminal as short as possible. At the same time it is important to establish the terminal without affecting other activities in the port.

Photo: Google Map

Figure 42: Possible terminal location in Brunsbüttel

12.8.1.1 Risks associated with LNG

The main hazards associated with LNG result from its cryogenic temperature, flammability and vapour dispersion characteristics. People who come into contact with LNG and are exposed to the cryogenic temperatures will suffer serious burns, while mechanical structures may fail and collapse. As a liquid, LNG will neither burn nor explode, it is not toxic and it will evaporate rapidly. LNG is less hazardous than liquefied petroleum gas (LPG) and liquefied ethylene, which have higher specific gravities, a greater tendency to form explosive vapour clouds, a lower minimum ignition energy and a higher fundamental burning velocity. As a result, the long-term environmental impacts from an accidental LNG release are negligible if there is no ignition of the natural gas vapours.

LNG vaporizes quickly as it absorbs heat from the environment, and the resulting vapour is flammable when mixed in air at concentrations around 5 - 15% (volume basis). Its fire-related properties are comparable to other light hydrocarbon fuels. The only significant difference is that its molecular weight is considerably less than air, so once it warms above approximately -108 ºC it will become less dense than air, and tend to rise and disperse more rapidly.

Typically, LNG released into the atmosphere will remain negatively buoyant (the cold LNG vapours are more dense than air and stay close to water or ground level) until after it disperses below its Lower Flammability Limit (LFL). If ignited in open (unconfined) areas, pure methane is not known to generate damaging overpressures (explode). However, if some confinement of the vapour cloud occurs, methane can produce damaging overpressures. Confinement can occur within the ship or nearby structures, such as a building onshore or another ship.

If LNG is not ignited, the flammable vapour cloud drifts downwind until the effects of dispersion dilute the vapours below the flammable concentration. The downwind distance that flammable vapours may reach

Photo: Google Map

Figure 43: Industrial activities in Brunsbüttel

is a function of the volume of LNG spilled, the rate of the spill, and the prevailing weather conditions. A recent study[12] has shown that hazard zones up to 3 km can be expected.

The consequence of such a spill can be listed as follows:

- This will lead to the formation of a large surface pool of rapidly boiling LNG
- Potential rapid phase transition might occur but will not lead to long distance pressure impact
- The vapour cloud hugs the water surface during initial dispersion for its entire flammable extent
- After ignition at the cloud's edge flash fire will occur, flashing back to the source
- The LNG pool will be ignited by the flash fire, resulting in a pool fire
- Given the LNG burning rate, the pool is expected to quickly shrink to a sustainable size

To disperse a significant distance downwind, a vapour cloud must avoid ignition. It is noted that large releases from an LNG carrier would most likely be the result of a significant force to initiate the release (that is to puncture the outer hull, inner hull, and cargo tank). If a flammable gas cloud is ignited by the initiating event or by other ignition sources (for example, on the ship, nearby vessels, or onshore), the flame will burn back to the vapour source, and the flammable cloud would not travel a significant distance overland.

12.8.1.2 External risk to the terminal

The external factors can be divided in three different groups:

- Malicious activities
- Related technical disasters
- Natural disasters.

Natural disasters are typically earthquakes, which occur several times a year in Germany. These earthquakes are relatively weak, and will not be discussed further in this report.

[12] DNV Joint Industry Project. LNG Marine release Consequence Assessment, July 2004

The related technical disasters that can be identified are associated with aircraft crashes and the risk of a loss of containment involving surrounding companies. In this showcase project the largest airport near Brunsbüttel is Hamburg airport, located 63 km to the south east of the harbour. Smaller airports near Brunsbüttel include Bremerhaven Airport, Cuxhaven Airport, St. Peter Airport, and Heide-Buesum Airport.

Based on flight routes from Hamburg Airport, none of the flights below 15,000 ft will fly over the planned location of the LNG bunker terminal. It is expected that landing and take-off operations from the smaller airports near Brunsbüttel will not cross the planned location of the LNG bunker

Malicious activities, such as terrorist attacks, are also important factors to consider. In this showcase project, they are not discussed in detail because the probability of such events is believed to be negligible.

12.8.1.3 External risk from the terminal

The risks posed to the surrounding industrial and residential areas by the terminal and its associated activities are referred to as the external risk. This chapter will assess the nature of risk posed by the storage and loading facility at the terminal, the road transportation of LNG and any related nautical activities, to the nearby residential and industrial areas and the new office building.

Residential areas

The town of Brunsbüttel is home to 13,120 residents, spread over an area of 65.24 km2. The southern part of the Brunsbüttel is located approximately 700 meters from the middle of the Elbehafen. A possible large loss of containment event that could occur at the LNG bunker terminal is the rupture of a 1000 m^3 LNG storage tank. This loss of containment event could result in a flammable gas cloud which could be ignited over a distance of up to 900 meters. In this showcase project the three external factors listed above could result in a flammable gas cloud that could reach the residential area of Brunsbüttel South. However, the probability of this event is considered very unlikely. A more realistic and representative scenario could be a small leak in the LNG storage tank, which could result in lethal effects (1% lethality) within a distance of 50 meters.

Industrial companies

There are many activities in the Elbehafen itself and the surrounding area. The jetty in the Elbehafen has two loading arms for the unloading of crude oil and one loading arm for the unloading of LPG. Besides bulk goods, the Elbehafen also handles containers, heavy gear, and general cargo. The containers that are handled may contain dangerous goods, which mean that that employees involved in the handling process should already be aware of the hazards posed by dangerous goods. The employees working in the workshops and warehouse buildings do not work with dangerous goods.

Figure 44 provides a detailed overview of the different activities and buildings in the Elbehafen. Based on figures 42 and figure 44, the location of the LNG terminal will be close to existing buildings and storage facilities. In the previous section it was determined that small leaks from the LNG storage tank could result in lethal effects in the range of 50 meters.

Photo: Google Map

Figure 44: Detailed harbour layout

At present it is not possible to assess the consequences of a loss of containment from the LNG import and bunker facility, since the flow rate through the piping and loading arms is unknown.

Buildings and road transport

The new office building in the port is located a short distance from the planned LNG bunker terminal in the Elbehafen. The location of the bunkering terminal was illustrated in section 12.8 Figure 42. In case of a loss of containment from the LNG storage facility, the building and people inside could be affected. In the previous section it was determined that small leaks from the LNG storage tank could result in lethal effects in the range of 50 meters.

The port is serviced by an efficient transport network of truck, rail, feeder, sea vessels and barges. It is assumed in this report that LNG is received and exported by LNG trucks. Figure 45 shows the road infrastructure surrounding the LNG terminal. There is a direct road to the LNG bunker terminal which will not run through residential and industrial areas, except for the Elbehafen. This means that importing and exporting LNG by truck will not significantly increase the risk to the people in the residential and industrial areas

Photo: Google Map

Figure 45: Roads in surrounding of the LNG bunker terminal

12.8.2 Space requirements for the terminal

The space required is related to the size of the terminal, which based on this showcase is approximately 50m X 60m. It will be necessary to analyse the soil conditions at the intended terminal location as the tanks and onsite equipment are heavy (a 1 000m^3 tank is approximately 21 000kg (Chart Ferox)).

In addition to the area required for the tank farm, space is also required for the fixed bunkering lines and the bunkering arrangements at the pier.

12.8.3 Conflicts with surrounding neighbours

It is important to consider potential conflicts with surrounding neighbours. In Brunsbüttel there are many existing industrial operations in the area. Most of these activities are clustered in and around the ChemCoast Park, which is the largest industrial area in Schleswig-Holstein. Figure 46 shows the industrial activities in the area surrounding Brunsbüttel. The different companies are indicated by numbers. Most of the companies are part of the ChemCoast Park.

Photo: Google Map

Figure 46: Industrial activities at Brunsbüttel

The company that may have a potential external effect on the LNG bunker terminal is number seven, located approximately 1 km from the Elbehafen. This is an import terminal for storing and handling of liquid petroleum gas (LPG). The liquefied gas is delivered by tankers to the Elbe port and pumped via a pipeline into one atmospheric tank and three mounded tanks, from where it is subsequently transported by rail and road tankers. It is not expected that loss of containment events from the mounted tank would affect the LNG bunker terminal since a BLEVE[13] scenario could not occur (because the tanks are mounded). Although the terminal storage tanks are located approximately 1 km from the Elbehafen, the import facility itself is in the Elbehafen. Loss of containment events at the import facility could result in damage to the LNG bunker terminal. It is difficult to assess the scale of the damage since the flow rates and specific characteristics of the import facility are unknown.

131 A boiling liquid expanding vapor explosion (BLEVE) is an explosion caused by the rupture of a vessel containing a pressurized liquid above its boiling point. If a vessel partly filled with liquid with vapor above filling the remainder of the container, is ruptured—for example, due to corrosion, or failure under pressure—the vapor portion may rapidly leak, lowering the pressure inside the container. This sudden drop in pressure inside the container causes violent boiling of the liquid, which rapidly liberates large amounts of vapor. The pressure of this vapor can be extremely high, causing a significant wave of overpressure (an explosion) which may completely destroy the storage vessel and project fragments over the surrounding area.

12.8.4 Terminal layout

Figure 17 provides an illustration of a terminal consisting of 3 x 1000m^3 pressurised tanks. Note, this example does not include the regasification unit that would be required if the terminal was part of the local gas distribution system. A 3 x 1000m^3 terminal can be filled with approximately 1,200 tonnes of LNG, or 18 GWh. The size of such an installation will be approximately 50m x 60m and this standard layout could be adapted to local conditions. The terminal is configured with all connections and valves at one end and, for safety purposes, an accumulation pool is also provided at that end of the terminal. In the unlikely event of a leakage of LNG, the liquid would be collected in this pool. There will be safety and EX zones around the accumulation pool. This area will be within an enclosure and there will be restrictions on all activities that may involve ignition sources.

An insulated LNG pipeline, probably submerged in a duct, connects the terminal with the ship connection point at the jetty. There is also a safety zone around the connection point, and an evacuation zone around the terminal, the size of which would be based on the risk assessment that had been carried out. This evacuation zone is prepared for emergencies in the event of an incident at the terminal.

Figure 47 provides an example of a 3 x 1 000m^3 terminal with truck filling facilities.

12.9 Pilot study

12.9.1 Foundation for investment decision in the show case

In this showcase the basic set-up for the LNG terminal will be as described in the following sections.

Figure 47: Terminal layout

12.9.1.1 Assumptions

The terminal will consist of 5 X 1 000m³ tanks. It is assumed that the bunkering will be done via pipe line and flexible hoses and/or bunkering arms. It is also assumed that the LNG will be shipped from a LNG import terminal to Brunsbüttel via a small scale LNG tanker with 3 500m³ loading capacity.

No maintenance and operating costs are included.

12.9.1.2 Profitability estimation/volumes

In this showcase three scenarios for annual bunker volumes are assumed. It is likely that a terminal will have some smaller start-up volumes and at the same time the annual volumes are likely to grow. As such, the assumed annual volumes are as shown in Table 19.

	Annual amount	Annual amount	Annual amount
Annual LNG in m³	45 000	91 000	182 000
Annual LNG in tonne	20 000	40 000	80 000
Annual LNG in MWh	300 000	600 000	1 200 000

Table 19: Annual amount

12.9.1.3 Transportation costs

The transportation costs will depend on several conditions. For example, the sailing distance from the import terminal to Brunsbüttel is critical. According to Gas LNG Europe there are 26 import terminals in Europe as of 2011 (http://www.lngeurope.nl/content_home.php).

The sailing distance from the Gate terminal in Rotterdam to Brunsbüttel is approximately 270 nautical miles. The sailing distance from Bilbao is approximately 1 000 nautical miles. Assuming a speed of 13 knots, these two voyages will take approximately 0,9 days and 3,2 days one way respectively.

Another important consideration is the size of the LNG tanker and the size of the terminal. Loading and discharging a full tanker is the most economical operation. Loading and discharging half a tanker increases the cost of transportation by nearly 100% per unit discharged.

	20 000 t/year	40 000 t/year	80 000 t/year
Sailing time	50 days	100 days	200 days
Time in port, inactive	310 days	260 days	160 days
Numbers of discharging	15 times	29 times	58 times
Typical annual TC cost incl. fuel	€ 3 750 000	€ 4 000 000	€ 4 520 000
Loading tariffs	€ 1 200 000	€ 2 300 000	€ 4 600 000
SUM	€ 5 000 000	€ 6 300 000	€ 9 100 000
Cost pr MWh	€ 17,0	€ 11,0	€ 8,0

Table 20: Annual cost

An optimal logistical solution is essential for keeping prices as low as possible. Table 20 illustrates the point that small volumes and high fixed costs will result in high transportation costs. Smaller vessels will probably have lower time charter costs, but higher harbour dues calculated by volume per loading. In this example indicative tariffs, subject to Belgian federal energy regulator (CREG) approval from the commissioning of the 2nd Jetty, have been used. In addition there will some harbour dues levied for loading and discharging in port.

12.9.1.4 Investment costs, including bunkering

Based on this showcase project the complete tank farm and fixed bunkering lines are assumed to cost approximately 15 million Euros. This includes ground work, engineering and tank farm investment. The payback time for the investment amount has not been taken in to consideration. This business decision will be made on a case by case basis.

If an interest rate of 12 % is assumed, with an annual volume of 40 000 tonnes, the cost of the terminal would be in the range of 2 - 3 Euro/MWh, with a payback period of 10-20 years. With an annual throughput volume of 20 000 tonnes, the cost would be between 5 - 6 Euro/MWh.

12.10 Bunkering in Brunsbüttel

12.10.1 First steps

After the purchase contract has been signed and capacity, price, amount and quality have been agreed, the LNG buyer must still go through a thorough control process, before the LNG seller can fulfil their part of the agreement. The Brunsbüttel showcase will provide a guide to the bunkering procedures and routines for filling up with LNG at the terminal.

12.10.2 Aspects in advance of the bunkering

To minimize any safety hazards and lay-time in port, the owner or the Master of the vessel must provide documentation confirming the vessel is fit for LNG bunkering before the vessel may start proceeding to berth.

The documentation must include proof that the LNG-tanks, hose pipes and flanges are registered and approved for use by the LNG supplier, in this case Gasnor. The owner must also make sure that there is a responsible, English-speaking person onboard who will be in charge of training and all active bunkering procedures. The vessel itself must be in compliance with current ISO, IMO and EU certifications for LNG bunkering, such as the IMO IGF Interim Guidelines (International Gas Fuel) and, although not required, ideally the vessel would also comply with SIGGTO guidelines. Additional standards and ISO-regulations for the safe handling of LNG, are being developed for terminals and bunkering processes from ship-to-terminal, ship-to-ship and ship-to-truck. At present there are no official standards covering the hoses and break-away couplings used for LNG transfers, but operations should follow industry best practice while waiting for certification.

Detailed checklists will be required for the pre-bunkering, as well as for the actual bunkering and post-bunkering phases.

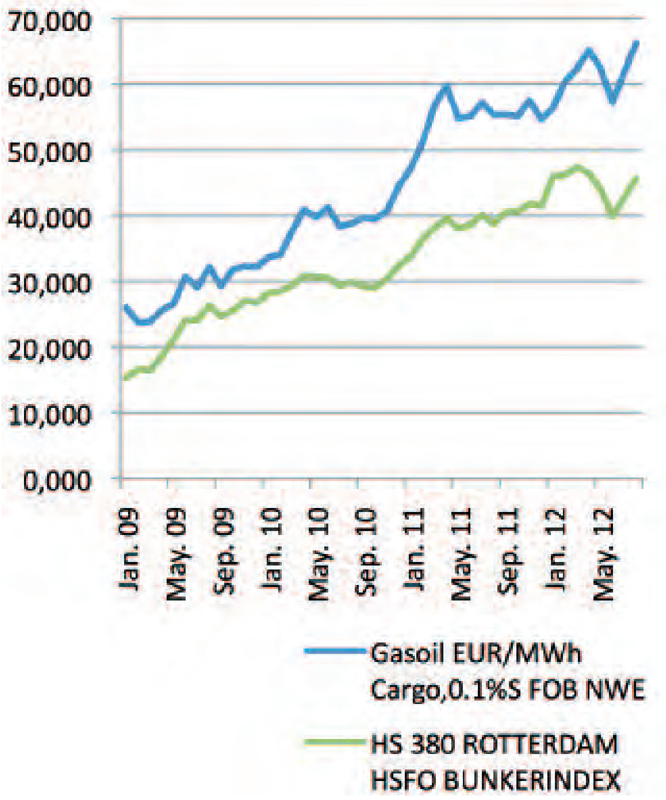


Figure 48: Platform supply vessel, Normand Arctic, arriving to bunker at Coast Centre Base (Source: Gasnor)

12.10.3 Preparations for bunkering

Firstly a communication link needs to be established between the receiving ship and the LNG terminal. This will allow the ship to advise Brunsbüttel Port authorities about its intended arrival at the LNG bunkering terminal. At this stage the amount of LNG, the estimated time of arrival and planned lay-time will be agreed with the potential customer. The terminal operator will allocate the most suitable time for the vessel to arrive at the bunker, taking into consideration current activity in the port and other ships waiting to bunker or occupying the quay side.

Prior to the vessel arriving at the quay, the ship and the terminal need to prepare for LNG bunkering operation. In an established small scale terminal it takes a relatively short time to prepare the tanks, pipes and hoses for bunkering, usually in the region of 15 minutes. If this is completed in advance the total bunkering stay should not exceed 2,5 hours. That includes half an hour mooring and coupling, and half an hour of decoupling and release once the bunkering is complete. The duration of the actual bunkering part, that is the flow of LNG from the terminal to the ship, would depend on the volume per time unit that the vessel is able to receive—assuming a pump of 500m^3/h this should take roughly two hours.

12.10.4 Responsibilities

Although the Master is responsible for all LNG bunkering operations, he may delegate the task to a certified, English-speaking member of staff who has received the necessary in-depth training in the handling of LNG. The demarcation line for bunkering responsibilities lies at the flange. The Master is responsible for everything shipside of the flange, and the port captain or the bunker facilitator, in this case Gasnor, is responsible for the bunkering procedures from the hose to the coupling on the vessel. To ensure a safe operation, it is essential that both ship and terminal crew follow the strict routines and checklists, as described above. This is especially important for the first bunkering operation, when the procedures for future bunkering operations are established.

12.10.5 First bunkering operation

The first time a vessel docks for bunkering, the terminal operators must check permits and documentation regarding the tanks and the carriage of cryogenic liquids. They must also check the routines put in place for carrying out checklists and preparations during subsequent bunkering operations. The Master is also responsible for making sure the vessel is ready to bunker LNG, in the same way that the terminal operators are responsible for preparing the bunker arm (see Figure 49) or the hoses that will be used for the bunkering process. Checklists must be signed and passed to the port captain before bunkering can commence and after bunkering has been completed. Checklists must be in English and

Photo: Germanischer Lloyds/CNSS

Figure 49: Example of an LNG bunkering

contain details about safety procedures, practical couplings, and the quantities and qualities of LNG bunkered.

A safe job analysis must be carried out by the terminal operator (Gasnor), ensuring that all procedures and steps are explained in a clear manner and are completely understood by the person in charge of the bunkering operation on the vessel side. The aim of the procedures is to avoid any unexpected occurrences during bunkering.

12.10.6 Equipment

Equipment for measuring the LNG pressure, flow (a flow meter), quality (chromatograph) and temperature is installed on the terminal side, and occasionally also on the vessel.

According to the 'LNG Bunkering Ship to Ship Procedure' report, which it is assumed would also cover ship-to-terminal transfers to some extent, certain equipment is required for the safe transfer of LNG. This includes hoses specially designed for cryogenic liquids, which must be the correct length and size to avoid over-stressing, with drip-free hose connections, and quick-connect couplings (see Figure 50). All hoses must be clearly marked and have different pressure measuring systems, break-away couplings on the LNG hose, good quality mooring lines and winches, sufficient light sources, insulated steel trays on the ship beneath the LNG and vapour return manifolds, gas detectors in enclosed or semi-enclosed areas around the bunker area, and finally a gas quality measuring tool.

Photo:

Figure 50: Example of a quick-connect coupling

12.10.7 Subsequent bunkering operations

As per the first bunkering operation, the procedure must begin with good communication between the approaching vessel and the bunkering terminal to facilitate safe berthing. This also ensures the secure handling of the equipment needed to start, operate and complete the transfer of LNG from the terminal to the vessel. Checklists based on the instructions from the initial bunkering operation must be completed and returned before any LNG can be released, and must also be completed after the bunkering operation is over. Post bunkering safe decoupling must be ensured to eliminate any leakage of LNG into the atmosphere. At present no completely leak-proof valve exists, however break-away couplings are an option and are being considered for LNG bunkering.

A well planned and efficient bunkering process minimizes time spent in port—a crucial point in the overall economy of the ship's operation.

12.10.8 After bunkering

Documentation detailing the amount and quality of LNG bunkered must be produced by the terminal operators, and compared against the requested amount in the LNG purchase agreement. Both the vessel and the terminal operators will check and sign the documentation at the end of the bunkering process. This will serve as written acknowledgement of the successful completion of the LNG transfer.

12.10.9 Quality and quantity of LNG

Determining the quantity of LNG bunkered and the subsequent payment request submitted will depend on the flow meters installed in the tanks and/or hoses on the quay. Initially payment is likely to be for a fixed amount over a specific time period, but the more frequent LNG bunkering becomes, there more likely it will develop into an oil bunkering or petrol filling pay-as-you-go system.

Although the flow meter registers the stream of gas running through the tank or hoses, it cannot assess the quality of the LNG, that is the methane content and purity of the gas. An analysis programme, such as a gas chromatograph that tracks the specifications of the gas, can assess the quality of the LNG. The gas analysis can be carried out in either the supply gas terminal or at the bunker station.

Flow meters and gas chromatographs can determine the exact volume and energy content of the gas taken expressed in MWh. A system that provides an automatic reading of the flow meter and quality analysis will serve as a receipt for the LNG bunker delivery.

With regards to the quantity and speed of LNG supplied to vessels, this depends on the characteristics of the pump. Although some pumps can handle as much as 1 000m^3/h, the pump systems must be compatible with the receiving channel on the vessel. In most cases different pump sizes will be used depending on the vessel size and intake equipment on board.

13 Findings

The following chapter summarises the findings for the various stakeholders involved in the CNSS WP4 LNG showcase project. The findings are primarily directed at politicians, relevant authorities and other decision makers but also to other relevant stakeholders such as NGOs, gas suppliers, ship owners and so on.

13.1 Regulatory

Shipping is an international business and it is important that the legislators consider this when addressing the regulatory demands related to the development of LNG as marine fuel.

- CNSS recognises the need for stakeholders to facilitate and promote the development of general, international solutions for the future LNG regulatory framework through organisations and regulatory bodies such as:
- IMO
  - IGC
  - IGF
  - STCW
- ISO
  - TC67 WG10 PT1
- IAPH/WPCI
  - On-going standardization of regulation between ports including accreditation schemes for LNG bunkering companies

CNSS stress that the legislators should avoid local, regional or national regulations and procedures whenever possible.

13.2 Commercial

Based on the commercial, regulatory and infrastructural framework for large scale LNG distribution systems in Europe, the availability of small quantities of commercial LNG is limited. CNSS therefore advocate the promotion of physical and commercial trading platforms to support small-scale and short-term LNG trade. Such a development will increase the market transparency and reduce the entry barriers for both suppliers and consumers of LNG in relation to the maritime markets.

There is both a perceived and real commercial risk for early the adopters of LNG as marine fuel. To minimise this risk, and make early adoption more attractive, it is important that the politicians and bureaucrats of Europe are consistent and stick to given promises and statements such as the introduction of the ECA rules from the 1st of January 2015. Based on the strengthened financial situation, especially in relation to shipping, a supply of low cost and accessible capital for conversions and new build ships will be necessary. It is also important to create a level playing field between the different methods of transportation.

Financial schemes will also be required for open infrastructure solutions including, but not limited to, the following:

- Break bulk facilities
- Regional terminals
- End supply units (bunker vessels/trucks/fixed bunkering stations)

To ensure efficient use of public funding, co-usage of LNG infrastructure should be promoted and any existing commercial and regulatory barriers should be addressed to facilitate this.

13.3 Environmental

To change the present marine fuel portfolio to include more LNG will generate significant environmental and health related gains from local, regional and global perspectives. To emphasize and further promote this change, CNSS advocates the following:

- Promote further expansion of the ECA zones both in Europe and elsewhere
- Initiate immediate actions to avoid the postponement of the global sulphur cut stated in MARPOL Annex VI from 2020 until 2025
- Facilitate and promote the development of incentive schemes for shipping such as the Norwegian NO_X fund
- Promote the extension of the European ECA with NO_X restrictions for all vessels by 2016 in additions to the present regulation which focuses on new vessels
- Promote port schemes and incentives that encourage the use LNG as marine fuel

13.4 Education, training and certification

Employing well-educated and trained professionals is essential to promote the safe, efficient and environmentally friendly use and supply of LNG as marine fuel. At present there is a significant shortage in the availability of suitably qualified personnel and no established regulatory framework. There are also few educational institutions with the necessary resources to provide the training.

The following report findings cover education, training and certification:

- Since shipping is an international business it is essential to promote and facilitate common international solutions with respect to training and education for crew on board IGF-, IWS-as well as bunker vessels. The same goes for crews operating LNG trucks and bunkering facilities. Local and regional demands may contradict some of these initiatives.

- Immediate action by member states will be necessary before the IMO STW44 in May 2013, concerning education and training requirements of IGF vessels, if such demands are to be submitted to the STCW convention within a reasonable timeframe.

- Facilitate and promote the development of alternative but general training and certification schemes for LNG bunker vessels crew to avoid crew shortages and/or a situation where bunker vessels are operated by crew without appropriate training and education.

- A common accreditation scheme, like the Port of Antwerp, in ports for LNG suppliers will promote the safe, efficient and environmentally friendly supply of LNG as marine fuel.

- Many indirectly involved professions will also be affected by the introduction of LNG as marine fuel. An inventory of demand for additional knowledge to be supplied by different professional groups should also be created.

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Appendices

Appendix A	LNG Bunkering from Bunker vessel in port of Hamburg
Appendix B	Navigational Safety Study on LNG-Tanker and LNG-Bunker Supply Vessel operation at Port of Hamburg
Appendix C	Rules and regulations of the report modalities for the provisioning of LNG as shipping fuel in Flemish ports

The appendixes are supplied as separate documents. For PDF-files, see http://www.cnss.no.

CNSS: Competitive Marine Transport Services and Reduction of Emissions – a North Sea Model

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