LNG FOR SHORT SEA SHIPPING

Public Report: LNG applications for Short Sea Shipping (LNGSSS)

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Project no. TKIG01034

Project data

Project number:	*TKIG01034*
Project title:	*LNG Applications for Short Sea Shipping (LNGSSS)*
Project leader:	*Koers & Vaart B.V.*
Project participants:	*Bureau Veritas, CMTI, Cofely, Conoship, Cryotek, Damen, Econosto, Lloyds Register, LNG24, Meyer Werft, Pon Power, Rolls Royce, Sandfirden Technics, VIV, Wagenborg, Wartsila*
Project duration:	*01-01-2013 until 30-06-2015*
Publication date:	*08-09-2015*

Overview

Summary

LNG as an alternative marine fuel offers excellent opportunities for a substantial reduction of harmful emissions for Short Sea Shipping. However, lack of knowledge about LNG, the financial risks and an immature LNG infrastructure prevent ship owners to switch from heavy oil or gas oil to LNG. The project LNG Applications for Short Sea Shipping (LNG SSS) investigates this issue in an integrated manner via an intensive co-operation between all 17 partners in the project consortium.

More than 40% of all transport within the EU takes place by sea. The Dutch short sea shipping sector, with some 1,000 short sea ships is the second European player behind leader Germany. The international pressure on shipping to emit less harmful substances is enormous. LNG as an alternative fuel for heavy oil or gas oil offers potential opportunities. But those opportunities and practical implications for many parties in the industry are still unclear.

Across the entire supply chain from shipping companies to manufacturers there are still many challenges to overcome before the wide use of LNG in Short Sea Shipping will be possible. This project involves a feasibility study with an integral approach to the feasibility of LNG as fuel in the Short Sea Shipping sector. It supports the development of an LNG supply chain for the sector.

The project consists of five work packages:
WP1 – Project management for effective coordination of all activities.
WP2 – Operational aspects, safety aspects, LNG infrastructure, distribution and fuel prices are studied based on the current state of the art.
WP3 – Business cases with regard to LNG storage systems, bunkering and gas- and DF engines.
WP4 – System design for Short Sea Shipping.
WP5 – Economic analysis, evaluation and reporting of results.

Clear conclusions and recommendations on the development of an LNG supply chain are drawn, from LNG distribution to the operational use on short sea ships. Consequently this project contributes to a reduction of harmful emissions on short sea ships.

Introduction

The Dutch gas industry plays an important role in Europe with a substantial low and high caloric gas network. Although LNG offers several opportunities for strengthening the Dutch position as a major gas player, the LNG infrastructure in The Netherlands is not fully developed.

Major players in the downstream LNG supply chain are presently developing LNG as a transport fuel for maritime applications in The Netherlands. LNG technology for logistics, bunkering, ships installations and marine engines is available and/or under development.

It is still a challenge to integrate these separate technical solutions in the entire supply chain and to develop ships sailing on LNG as well as LNG bunkering solutions that comply with regulations and are also economically attractive.

There are still major challenges in the interfacing of state of the art LNG systems. It requires an integrated approach from the LNG infrastructure provider, to the ship-owner, shipyard and LNG system suppliers, including regulators and classification societies. This includes amongst others, gas quality, pricing, bunkering, methane slip, engine performance as well as ships and LNG system regulations.

This project supports the development of the downstream LNG supply chain, with a focus on the development from both the ship owners’ and LNG bunker operator perspective. Therefore the major stakeholders for developing the maritime LNG supply chain joined forces to actively share information, knowledge and expertise in order to overcome this market failure related to imperfect and asymmetric information.

Objectives

This document includes a technical feasibility project preparatory to industrial research (WP2), followed by an experimental development phase, where proof of concepts and systems designs for small scale LNG infrastructures and short sea shipping are developed (WP3 and WP4).

WP2 provides insight in the current operational and safety requirements from ship-owners’ and LNG bunker operators’ view and gives input for (industrial) research for universities and knowledge institutes.

WP3 and WP4 provides solutions for operational and safety issues regarding LNG infrastructure, distribution, bunkering and LNG systems on board for both newly constructed as well as existing short sea ships fitted with full LNG or dual fuel engines.

The project has a focus on two interlinked parts: the ships’ LNG system design, installation and operation on the one hand and the downstream LNG supply chain infrastructure on the other hand. It is primarily carried out from the ship-owners’ and the LNG bunker operators’ perspective and how LNG can become a viable option for both parties.

The analysis includes a further assessment of selected compliance strategies from a ship owner view. In this perspective, a ship owner is interested in the price and availability of LNG compared to other options like MGO or HFO and scrubbers. The ship owners options are evaluated including total cost of ownership (TCO), required and existing standards and safety aspects.

The technical and economic feasibility for different potential LNG suppliers and other stakeholders is assessed, including the dividing line between ports, government authorities, the energy industry and other private operators from an investment and operational point of view. Furthermore an identification of key characteristics of locations for filling stations/bunkering facilities is made as well as possible connections to inland waterways.

The project results in the formulation of draft principles and preconditions for further development of components and subsystems both on board and ashore. In addition, the project provides information for refining the international and classification rules and regulations with regard to LNG on board ships and LNG bunker operators as well as recommendations for safe installation and operation of LNG systems on board and ashore with regard to maritime operations.

This feasibility project contributes to:

- Collaboration in the downstream LNG chain
- Transforming existing knowledge and experience into practical solutions and relevant (fundamental) research questions and innovations
- Definition of feasible and safe small scale maritime LNG terminals and LNG installations on board
- Safer and more profitable operation of LNG terminals and LNG installations on board
- Improving the image of the maritime and LNG industry
- Increasing the environmental and social involvement of the maritime and LNG sector

The consortium developed requirements for regulations and standards and also for proofs of concept, ship designs, systems and components for the application of LNG in the short sea shipping industry, leading to practical applications in short sea shipping.

Project results

WP1 – Project management

Project management during the project LNG applications for Short Sea Shipping was carried out by Koers & Vaart B.V. and supported by Netherlands Maritime Technology Foundation (NMTF - previously named CMTI). The work package project management comprises coordinating and supporting activities to run the project together with the consortium. During the project the focus has been on sharing new LNG and maritime knowledge between all the parties involved. This knowledge is obtained by each member of the consortium in other LNG projects like LNG for inland waterway vessels, LNG for ferries, LNG for land installations, safety regulations etc. creating a living body of knowledge and a community of practice.

A cooperation agreement was developed and undersigned by all 17 parties at the beginning of the project in March 2013 (see add. WP1). This agreement was updated in February 2014 when Cryonorm projects was replaced by Cryotek (see add. WP1).

In a period of about two and a half years 18 general meetings for all participants were held. On some of these meetings external experts were invited to share information on technical and economic issues or developments with regard to LNG on board of ships. Apart from these meetings several smaller meetings between participants were held in order to exchange specific data and experiences. Some of the partners also participated in LNG projects for inland shipping, ferries and land installations during the last 30 months.

Several initiatives are presently taking off between different suppliers in LNG for Short Sea Shipping to increase the feasibility of LNG as a transport fuel for shipping in general and short sea shipping in particular.

Due to the cooperative attitude and efforts of all participants the proposed planning and budget allocation could be met. A few participants were not always able to attend the general meetings due to busy schedules and other priorities. However an overall average attendance to the general meetings of 12 companies was inspiring for all parties.

The consortium did not only focus on the technical feasibility of LNG as a transport fuel, but also on the economic feasibility in comparison with HFO and scrubbers and MGO. This complicated the project considerably with regard to EU competition laws. A non-disclosure agreement was prepared with the input of several major players in the consortium. This process included the involvement of lawyers of different companies and an external lawyer and resulted in a delay of the project of about six months. This delay was noted timely and an extension of the project was requested to RVO. RVO granted the project an extension of 6 months. The NDA is signed by all parties involved. (see add. WP 1))

All issues addressed in the project plan have been covered during the project. A calculation model was developed by Wagenborg and LNG24 with the input of the other partners. This calculation model provides insight in the profitability of HFO and scrubber technology versus LNG or MGO as a transport fuel. (see add. WP 2.1)

The technical data for this calculation model was also provided by all relevant partners in the consortium. Financial and economic data that is general available in the public domain like HFO and MGO fuel prices are included in the model. Financial and economic data which is not available in the public domain is not published for safety reasons with regard to EU competition law. Every partner can use the model and include its own data in order to investigate what solution might be feasible in a certain condition. The calculation model (without any commercial data included) can be made available for other stakeholders in the development of the maritime LNG chain.

WP2 – State of the art in technology and regulations

On the basis of the available data on the state of the art, technical starting points for the business case for short sea shipping and LNG terminals are determined.

WP 2.1. – Operational aspects

The operational aspects of LNG terminals with regard to maritime operations as well as the installation and use of LNG systems on board of ships were evaluated from different viewpoints. The ship owner, shipyard, system supplier, engine manufacturer, classification societies and infrastructural service providers (including LNG transport companies) brought in knowledge and experience with regard to the handling and use of LNG downstream the LNG supply chain and the use of LNG on board of ships. Operational aspects are primarily regarded from a ship owners perspective.

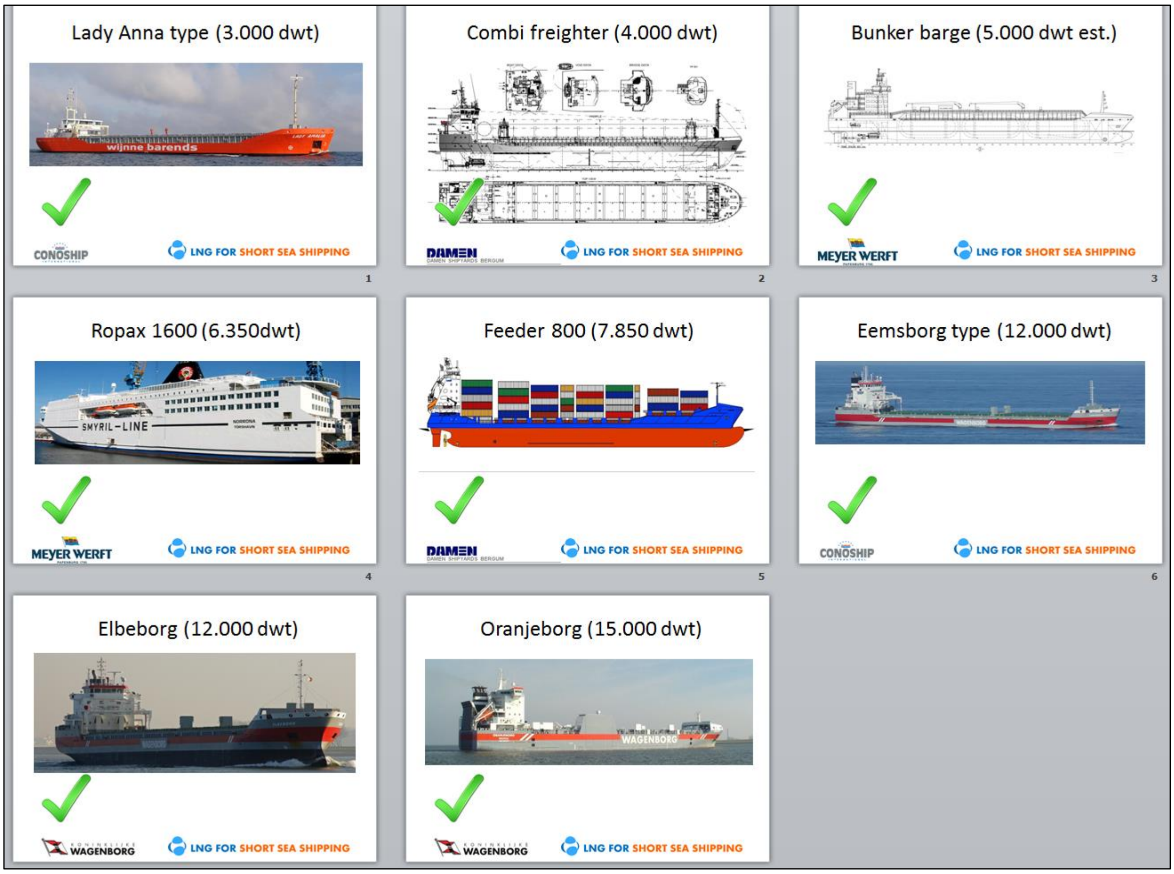
The ship owners' option for LNG is assessed in more detail. Analyses covered both the operational aspects for new built vessels and retrofitting of vessels with LNG. In both situations full LNG as well as dual fuel options were analysed.

Another option for ship owners is using the same engines with cleaner fuels, especially low sulphur gas oil. The operational consequences and the expected price development on these fuels are studied and predicted.

The final option for ship owners is the use of traditional HFO engines and installing scrubbers. This mainly concerns the costs and implications on operations when installing a scrubber. The assessment also estimated the availability of scrubbers on the market and the charges that are linked to waste management.

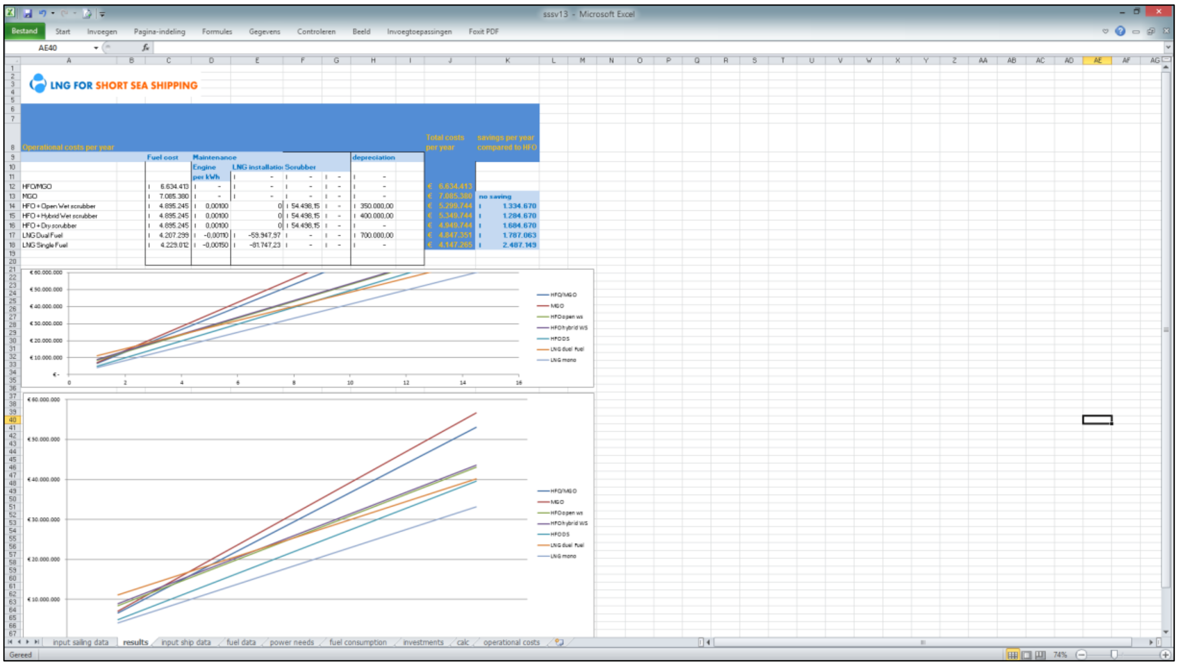
On a regular basis meetings were planned with consortium participants coordinated by the project leader. This work package resulted in different scenarios for short sea shipping trades and insight in the various energy demands on board. Based on interviews with ship owners and in consultation with the consortium participants different operational sailing profiles for short sea ships were determined for further evaluation. From the LNG terminal operators point of view several operational scenario's for bunkering were determined and further defined.

Wagenborg acted as the project leader for WP2.1. The first activity was to establish a long list of vessels that qualify for the use of LNG as a transport fuel. From this long list 8 vessels were selected for further investigation. Graph 2-1-1 (See add. WP 2.1).



Graph 2-1-1: Eight ship types selected for comparison of LNG – HFO scrubber - MGO

In close co-operation between Wagenborg and LNG24 a calculation model was developed in which operational, technical and cost data for various scenarios can be compared. Graph 2-1-2 (See add. WP 2.1)



Graph 2-1-2 Impression of Calculation model for comparison of different fuel and engine options

WP 2.2 – Safety aspects (including education)

The rules and regulations for the introduction of LNG as a transport fuel on board ships have to be developed with regard to the specific maritime needs and requirements. In consultation with national and local governments as well as the classification societies Bureau Veritas and Lloyds Register technical solutions and adjustments are proposed in order to obtain safe and optimal LNG system solutions, both on board ships as well as on LNG terminals with regard to maritime operations. For this work package Bureau Veritas has acted as a project leader. Bureau Veritas is also part of the Dutch national delegation at IMO for issues concerning LNG as a transport fuel (See add WP 2.2.1).

Organizations, authorities and also the private sector are investigating possibilities to use LNG as a transport fuel as a response to IMOs regulations on sulphur limit in SECAs that is put into force from January 2015. A potential change in bunker fuel requires rules and regulations to facilitate infrastructure, handling of LNG as a fuel, and the coverage of safety and security issues.

Regulations and rules in the shipping industry are set on an international, global basis. There are many organizations dealing with shipping in different ways, contributing to international shipping development with best practices, accepted standards and regulations.

- The International Maritime Organization (IMO) (MARPOL/SOLAS)
- The International Organization for Standardization (ISO)
- The Society of International Gas Tanker and Terminal Operators (SIGTTO)
- The International Group of Liquefied Natural Gas Importer (GIIGNL)
- The Oil Companies International Marine Forum (OCIMF)

There are rules and regulations regarding equipment for LNG, design and manufacturing of cargo containers and storage facilities for LNG and transportation of dangerous goods that vary depending on national standards. There is a growing need for international standards to facilitate the use of LNG as bunker fuel on a global level. An example is the impact strength as displayed in Graph 2-2-1

Graph 2-2-1 Model test of Impact strength of LNG fuel tanks

Another important safety aspect is the development of rules and regulations concerning the human factor. The ship's crew must be educated/ trained adequately in the use of LNG. The topic 'training' is essential and often mentioned as governmental requirement when ship owners apply to equip their ships with LNG as a transport fuel. Handling LNG requires specific knowledge and skills. The training includes the safety standards and regulations for LNG, bunker procedures and measures to be taken in case of calamities. The subject also includes the engines, the LNG storage tanks and the LNG system. Classification societies, suppliers and operators have contributed to a baseline document for adequate LNG training (see add. WP 2.2.2).

Early and good communication of safety issues with government authorities, media and the public includes:

- An accurate safety analysis and adequate time to communicate this to the public and the authorities
- Providing a positive track record of the companies designing and building the LNG infrastructures and marine systems and proof of safe working procedures
- It is important to openly communicate to the public the advantages of LNG as a fuel, e.g. reduced emissions and reduced engine noise

The shipbuilding and combustion engine associations play a vital role in communicating about the benefits and safety of LNG. The result of this work package is a safety analyses for short sea ships and LNG terminals (see add. WP 2.2.1) as well as a baseline document for training of personnel working with LNG in marine operations (see add. WP 2.2.2). The safety analysis can be used to clearly communicate the benefits of LNG to relevant authorities, media and the public in order to raise positive support for LNG in short sea shipping.

When new rules and regulations are set out for a developing market, the main focus is to minimize risks for human and environment. For the use of LNG, this is accomplished by performing hazid identification sessions, describing the current state of the art technology and standardization of equipment and procedures.

Three main sections are acknowledged in this development of rules and regulations, being the final user (ship), the supplier (bunkering facility) and the interface between both. For the user side, this work is mainly done within the International Maritime Organisation (IMO), a subsidiary body of the United Nations. During the last couple of years, and mainly during the course of this project, these requirements are set out in a code of safety for ships using gases or low-flashpoint fuels, in short the IGF code. Within this code, requirements are set out for the following items:

- Principles of engine room lay out (gas safe or emergency shut down)
- System requirements for the LNG containment systems (tanks and piping), conditioning systems (evaporators) and consumer systems (engines)
- Detection, monitoring and safety systems
- Fire fighting systems
- Training and operation
- Allowed configurations/locations

In this project an important issue was the allowed configuration and location of tanks. As the tanks will not be allowed to be positioned in locations affected by collision, the most likely position will be in the cargo area. This will impact the carrying capacity (deadweight) of the ship and therefore the earning capacity. Additionally, the costs of added training and maintenance has been addressed.

From the supplier side, the work is mainly done within the NEN committee together with the contribution of the harbour authorities and safety regions. The results are set out in the PGS 33 standards. These standards are prescribing the requirements for shore-to-shore delivery (PGS 33-1), shore-to-ship delivery (PGS 33-2) and ship-to-ship delivery (PGS 33-3, under development). These standards set out requirements for:

- Construction and installation of bunkering facilities
- Operation of bunkering facilities
- Survey and maintenance
- Internal and external safety

Especially the external safety standards within this PGS will affect the possible locations at which bunkering will be allowed. Although no major obstacles are put forward within these standards to set up bunker facilities, the availability of bunker facilities might affect the operational range of vessels or, alternatively, the amount of LNG to be carried on board. (see add. WP 2.3 and WP 2.4)

For the interface between both supplier and user, no dedicated regulations are set out yet. It should however be noted that both standards contain information and requirements to be taken into account for the safe bunker operations. Especially on the communication between both parties, the responsibilities and liabilities are mentioned.

Developments CEN

Finally it should be noted that, although of lesser importance to safety, a standard is under development to regulate the composition of the LNG (see add. WP 2.5.2).

WP 2.3 - LNG infrastructure

For this work package Cofely has acted as project leader. For the Netherlands and Germany the terminals in Rotterdam (Gate) and Zeebrugge (Fluxys), or Montoir (Montoir-de-Bretagney) are the most nearby terminals that can facilitate road trucks and small LNG carriers. These terminals primarily serve the gas grid with sometimes a secondary retail function for the energy market for industry clients who need LNG for their off-grid power systems. Therefore these terminals cannot be directly used for maritime purposes.

Graph 2-3-1 LNG import terminal and coverage

To facilitate marine customers a system of small- and medium-scale terminals, feeder and bunker ships bringing LNG from the import terminal to the small and medium-scale terminals and directly to the ships must be developed. An adequate number of small LNG terminals or bunker stations is important in bringing down the associated costs from a large terminal.

Large import terminals are developing and implementing medium scale infrastructures like LNG break-bulk storage and jetties, to supply LNG to feeder and bunker ships as well as truck loading facilities to load LNG tank trucks.

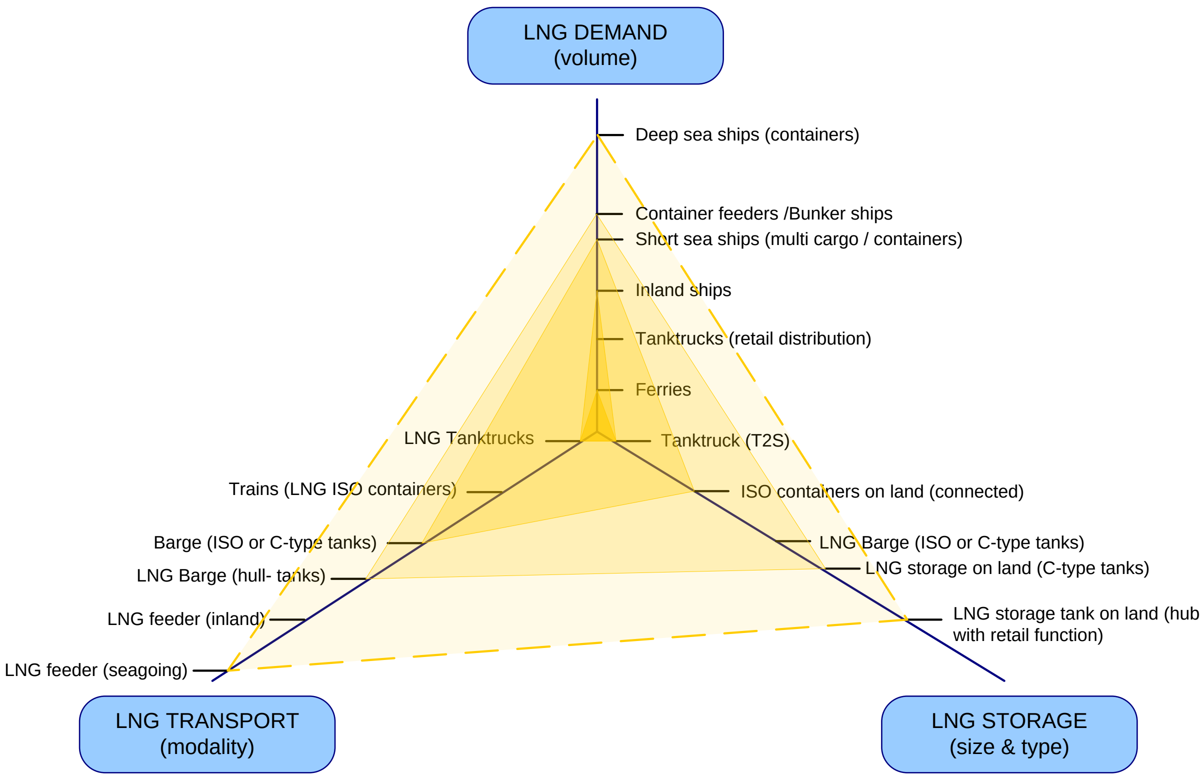
Medium sized LNG storage tank facilities are likely to develop in existing ports without their own LNG import terminal, in order to enable a main LNG basic infrastructure and to enable the retail function of LNG in these ports. This basic LNG distribution system, using small scale LNG distribution terminals in coastal port locations, can be supplied with barges or sea going vessels. From these small scale terminals, bunkering activities can be organized (also to surrounding ports) but also supply to the direct hinterland using road tankers to truck service stations along the major highways. Road risk congestions at the indicated coastal locations are not significant today. Ports with a rather small demand will have the LNG supplied by truck or ship from a nearby port or install an LNG storage tank with flexible LNG supply systems. These intermediate storages are mainly serviced by a tank truck filling which will be sufficient enough for serving small ferry operators and regular liner of short sea shipping or inland shipping traffic with a limited demand for LNG.

In Rotterdam, at the Gate-terminal, a break-bulk terminal is in development and expected to be in operation in the first half of 2016. In Dunkirk an LNG terminal is expected to be operational in 2015. Nearby, in Bremerhaven, Brunsbüttel and Hamburg small scale LNG facilities are also in development. Additionally, existing infrastructure is being expanded. In Zeebrugge additional berthing facilities are developed and the capacity for truck loading is increased from 3.000 to 5.000 trucks per year.

LNG Volume scenarios

To meet customer demands for using LNG as fuel, the need exists to develop and build the logistic chain and infrastructure for LNG in a modular way by starting with tank trucks to ensure the balance between volume demand and storage and supply capacity. LNG volume demand must be in balance with the development of LNG bunker storage due to the cryogenic characteristics of LNG.

Modelling the volume of LNG in the different logistic and customer scenarios (see the graph 2-3-2) concludes that there is a need to implement intermediate storages already in the medium LNG volume scenarios to meet the customer bunker profile demands and to create enough flexibility in the logistic chain. This means a market approach with a long term sustainable LNG market price and not a price scenario for the short term solution. A short term solution offers an optimal cost structure but would overlook the cost increasing consequences of an intermediate infrastructure solution. Only in very high volume scenarios the logistical cost component of the LNG price is expected to decrease.



Graph 2-3-2 Development of LNG volume scenarios

Investments needed to develop, build and operate small LNG infrastructure compared to LNG volume demand increase of different customers in an (port) area are not linear and not in harmony with each other. Volume demand of LNG as bunker fuel fitting the different bunker profiles of different customers, like ferries and short sea ships, can vary significantly with regard to total volume, bunker times and flow rates needed and number of bunkerings per client per year. To ensure an economic and sustainable development of the LNG infrastructure, flexibility, security of supply and competitive LNG pricing are important and will secure a feasible and stable LNG retail market development in the long-term.

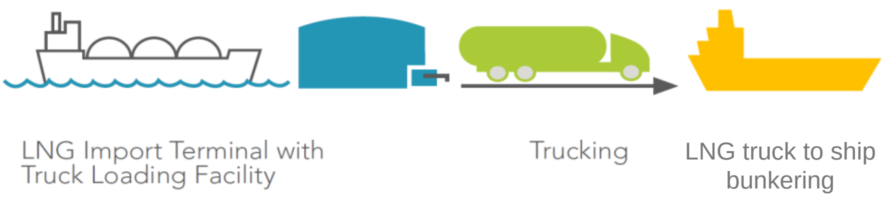
This conclusion underlines the need to approach the market with a long term 'sustainable LNG market price' and not a price scenario for the short term solution. Of course the development and pricing of LNG as bunker fuel will be influenced by the market itself and their customers.

Retailing supply chain

Currently, three main ways of supplying LNG as marine fuel to end-user can be discerned: supply of LNG directly by tank-trucks, via an intermediate storage and when volume demand of LNG increases, the use of regional hubs will be more sufficient. The general idea behind the three scenarios is to offer flexibility and stability in an economical way. Each scenario offers optimal customer flexibility combined with supplier stability and the investments needed will be in balance with overall LNG volume demand by the customers.

Trucks

The most flexible way of organizing LNG supply in a small (up to 1.200 tons/customer) market is by means of 18 - 22 tons (40 ft cryogenic container) tank trucks. From the import terminals in the coastal areas these trucks can reach a large number of European destinations.



Graph 2-3-3 Scenario tank trucks

Bunkering takes place on a designated area on the quay. Trucks can be deployed from 18 tons up until virtually all its multitudes as long as logistically and economically viable. This makes incremental up-scaling in case of growing demand very easy. A disadvantage of supply by truck is the batch size. Ideally a ship is supplied in multitudes of one truckload. Therefore the on board storage capacity, the consumption profile and the bunkering planning should be congruent. Each bunker location needs to be permitted, based on risk analyses and safety requirements. Thus, in a given region only a few approved quay-side bunkering locations will be available. Therefore the maximum number of ships that can be supplied with LNG by trucks in a certain area is limited. In that case an intermediate storage facility is necessary to meet the customer bunker requirements.

Intermediate solution/storage

The aim is finding the most optimized solution for bunkering LNG to ships, combining the existing available logistic equipment like tank trucks and LNG ISO containers in combination with a higher bunker flow. The solution for bunkering short sea ships is a high flow operation to the receiving ship to meet the customer bunker profiles. Generally a tank truck has a tank volume of 18 – 22 tons of

LNG and a pump capacity of ~ 10 - 11 tons/hour flow rate. To empty one tank truck trailer a bunker time of 2 – 3 hours is needed including the pre- and post- bunkering procedures for safety and custody transfer. Smaller sea ships like coasters generally need an LNG bunker capacity of ~ 60 – 150 tons of LNG in one bunker operation, depending on the size and type of ship. Higher flow rates are needed but still the flexibility of the tank trucks and ISO containers are necessary because of the low total LNG volume demand in the region.

If the regional consumption of LNG increases (above 5.000 tons/customer), the use of intermediate storage becomes necessary (see graph below). The intermediate storage is a quayside (or floating) storage and bunkering facility supplied by trucks.

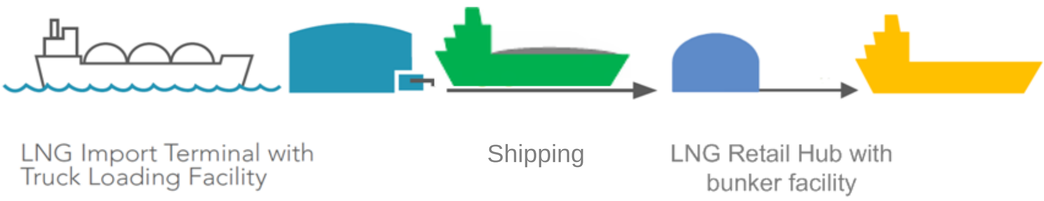
Graph 2-3-4 Scenario Intermediate storage

The storage has several advantages over the use of trucks. The loading rate, from storage to the ship, can be twice as high, thus reducing the customer loading time and increasing the number of loading sessions per day. Secondly, the intermediate storage can deliver quantities smaller or larger than a truck load. This makes the bunker planning easier from a customer point of view. Also the fact that bunkering can take place irrespective of the availability of supplying trucks and drivers is an advantage. The capacity of the storage is mainly dependent on the LNG consumption and therefore very location specific. In general 30 tons would be a minimal size. It is expected that research will show that ultimately, when LNG demand reaches maturity, a mid-scale LNG storage facility with ship bunkering and truck loading facilities will need to be realized. Prior to that, when LNG demand is in the early adoption and growth phase, it is expected that transportation of LNG and the fuelling of ships, trains and other possible consumers will be performed with tank trucks, mobile intermediate bunkering facilities and flexible small scale storage/bunkering facilities.

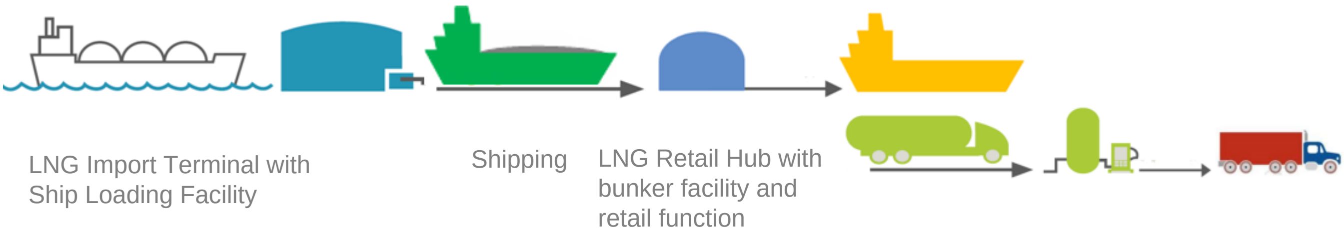
Additionally, a storage facility can also be equipped with a dispensing function for LNG or CNG trucks. As such, the intermediate storage facility is a stepping stone to the regional hub.

Regional hub

A regional hub will become worthwhile if the annual regional consumption exceeds 10.000 tons/year. The hub is capable of storing large amounts of LNG to supply a considerable amount of LNG for both ships and trucks. Initially the hub will be designed and dimensioned to supply the short-term customer base. A storage capacity of 350 - 500 tons would be sufficient for an annual consumption of 10.000 tons. Hubs can easily be expanded when executed with C-type storage tanks by adding extra storage tanks in case of increasing consumption. Additionally, when the intermediate LNG storage will function as a hub, the installation will be equipped with retail functions as tank truck loading for the delivery of LNG in the region to LNG stations and end users.



Graph 2-3-5 Scenario Regional hub



Graph 2-3-6 Scenario Regional hub and retail function

The hub will be supplied by small LNG carriers (500 - 4.000 tons). In general, unloading rates are 360 tons/hr. A small LNG hub can be filled in one to ten hours. Typical loading rates for customers are:

- Intermediate storage LNG loading volume: 45 tons/h
- LNG tank-truck loading volume: 12 tons/h
- LNG dispenser for heavy road trucks: 5 tons/h

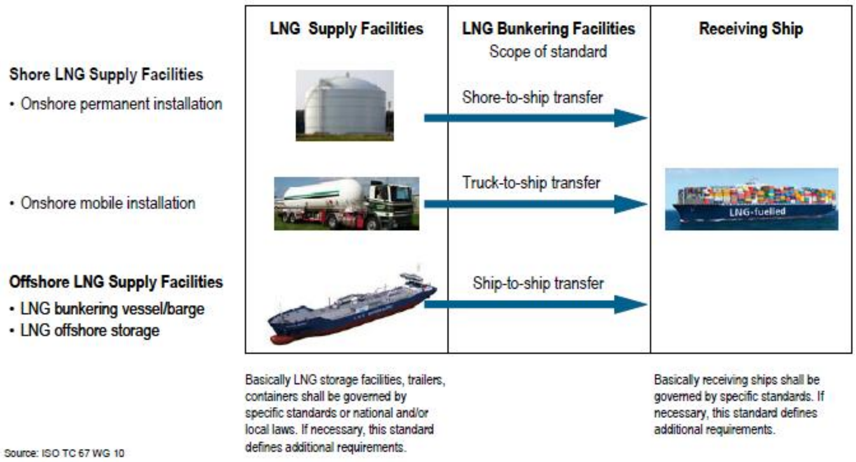
The hub is operated by specially trained personnel and the operations, maintenance and inspection procedures will continuously be developed based on up-to-date insights.

The small scale LNG supply chain

The small scale LNG supply chain (see graph below), contains various elements of transport and handling LNG related to onshore and maritime operations.

The following LNG supply modes are the most commonly known methods:

- Shore-to-ship (pipeline) transfer
- Truck-to-ship transfer
- Ship-to-ship transfer



Graph 2-3-7 Small scale LNG supply chain

In addition to the above mentioned methods, the use of portable tanks is being investigated. In the case of using portable tank systems, empty tanks will be unloaded and replaced by full portable tanks. In comparison to the above mentioned procedures, the reception of LNG as fuel consists of loading/unloading and connection/disconnection of the portable tank systems.

Conclusion

For decades LNG has been transported in large quantities from continent to continent. This market exists already for more than 60 years and its track record on safety and security of supply is impressive. The ambition is to take that expertise an important, sustainable step further right onto the small scale market.

Now the small scale LNG development and the use of LNG as a fuel is strongly moving ahead but still needs some time to become a mature market. Essentially solving infrastructural issues, secure the supply of LNG as a fuel, is one of the most important goals of the LNG supply companies for the retail market and has already become their core business.

The supply and infrastructure companies are able to offer a reliable and yet flexible LNG supply based on the customer requirements as described in the different scenarios. LNG infrastructure will be built in a modular way used as a commercial and sustainable means to provide LNG to end-customers, based on a long term vision and a sustainable relationship.

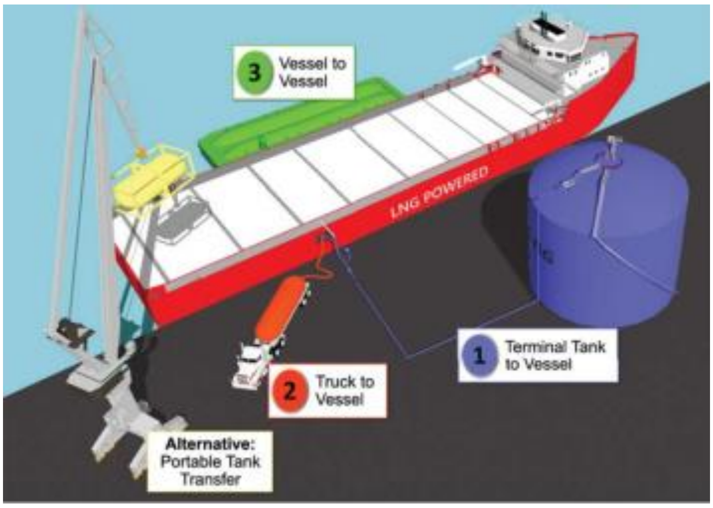
For now LNG supply and infrastructure companies are supporting their customers by supplying the LNG in an optimal way by trucks, small barges or modular (small) infrastructure developments, where investments will fit in the total retail price demanded by the customers. Long term commitments for supply of LNG to the shipping sector cannot be made yet, due to the immature infrastructure and short term pricing of LNG in the region. Therefore custom made short term contracts are set up with the customer to support them in their switch to LNG as fuel.

Drivers to support the development of LNG as fuel in the maritime sector are structural and consistent regulation to reduce harmful emission like SOX, NOX, PM and CO2 and regulating support from local governments. A supporting tax regime from EU governments to reduce air pollution or an

EU fund to support the switching cost to LNG for the maritime sector could help and increase the use of LNG substantially.

WP 2.4 - LNG distribution and bunkering

LNG 24 has been the project leader for work package 2.4 on LNG distribution and bunkering.



Graph 2-4-1 LNG distribution and bunkering options

Options for bunkering

The first initiating projects are supplied by tank trailers but this will be no sustainable option for the future. Only limited amounts of fuel can be carried by a tank trailers (50 m3) while an average volume seen by short seen ships is about 500 m3 of LNG.

However, it is a flexible solution since trucks can drive to different harbours where no LNG bunker infrastructure is yet available and refuel the ship. The safety margins however should be considered. It is not possible with respect to external safety margins to get an permit to refuel in every harbour. Another benefit is that no investment (besides the trailer) is needed in comparison with a terminal bunker location.

The Zeebrugge Terminal as well as the Rotterdam Gate terminal do have a truck loading facility. The procedures to get LNG are in such a way organized that a day in front of the delivery a slot need to be booked. Therefore the logistics have to be planned in a structured way. The slot fee contributes to 7,5 % of the total cost of one LNG truck delivery.

For ships that are sailing a fixed route a LNG bunker terminal is the best solution. Availability of fuel is guaranteed and not depending on the delivery by truck which can be delayed by traffic jams, weather conditions and or simple failures like a flat tire.

An investment is needed to establish a LNG bunker terminal, it is only feasible when one or more ships are regularly using the terminal for at least five to ten years period. Otherwise the depreciation of the terminal will generate such a high LNG price that the business case for the ship is not feasible. However operators of refuelling infrastructure are interested to invest in the terminal at their own risk with these conditions.

Regulations for establishing a LNG bunker terminal are available in The Netherlands (PGS33-2 for LNG bunkering stations) as well as the external safety distances. For a LNG bunker terminal a QRA has to be executed. Depending on the layout of the terminal the external safety distance is minimum 50 meters up to 75 or 100 depending on the safety feature of the LNG bunker terminal. If for example an automatic Emergency Shut Down (ESD) is used during unloading of the LNG it will reduce the safety distance in case of rupture of the unloading hose. Detailed information about the standard is publicly available (see add. WP 2.3 and WP 2.4).

The use of safety and security zones around the LNG bunkering operation are necessary to prevent the creation and spread of hazardous situations in case of an accident during bunkering. The two types of zones have different purposes and definitions. The purpose of a safety zone is to designate an area where only essential personnel with proper training are allowed to enter and where no sources of ignition are allowed.

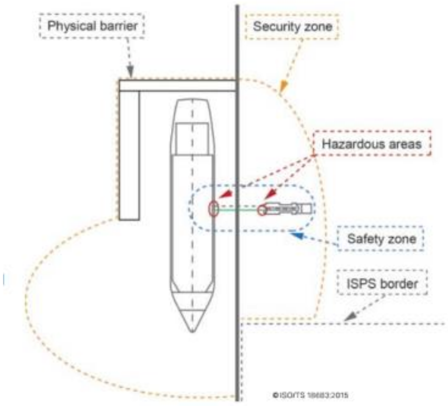
The purpose of the security zone is to create an area of sufficient size that keeps other vessels, vehicles, equipment, and cargo operations far enough away so that they pose little risk of damaging or interfering with the LNG bunkering system and equipment. This zone is intended to keep non-essential personnel on a safe distance so that injury by any hazardous incident during the bunkering operation is unlikely, and to make it difficult for a person to intentionally damage or interfere with the bunkering system and equipment. The supply of LNG to the terminal can be done by truck or by feeder vessels.

A third option to bunker short sea ships is by bunker vessel. This is the normal bunker operation for marine diesel. However the investments for a bunker vessel are at least ten times higher than for a LNG bunker terminal. The get a positive business case for the bunker vessel operator is very difficult in a starting market. However, four parties in The Netherlands already have design plans for a bunker vessel ready.

In general, LNG bunker ships are considered gas carriers, and the vessels are to meet the requirements of the IGC Code and applicable class requirements. The IGC Code is mandated by SOLAS and applicable to seagoing vessels in international trades. The regulatory challenge is for ships that will operate only in restricted or domestic services, in which case compliance with the IGC Code may not be required by the flag Administration or port authorities. The IGC Code is not applicable to barges so regulations from national administrations, port authorities and class requirements would apply. Therefore, for certain operating profiles and types of bunker vessels, early communications with the flag administration, port authorities and class are recommended.

The large scale terminal operators like Zeebrugge is using a slot fee of € 75.000,- independent of the amount of LNG taken from the terminal. An additional fee of € 0,18/MWh is applicable (See add. WP 2.4).

A future option is the use of transportable ISO tank containers. At the moment this option is not accepted by the classification societies. When a ship is build, the complete gas system is certified, including the gas tank. If a replaceable gas tank is used as fuel tank, the current regulations demand a new assessment of the gas system. This will be the case when replacing the gas storage. So the current regulations are not applicable for this situation. However the transport of ISO containers is already regulated by ADR an ADN, so the transport by road or rail or water is no problem. Putting several ISO containers on an inland barge is much cheaper than building a bunker barge.



Graph 2-4-2 LNG bunkering safety zones

The largest gap in respect to LNG bunkering is the lack of international guidelines, standards and recommendations in general for small scale LNG. There is a need to work pro-actively to propose international legislation for small scale LNG use. Uniform global standards regarding the use of LNG as fuel will ensure safe development of the industry which is of essence if investments are to be made.

The use of LNG has to allow for simultaneous activities such as loading and passenger (dis)embarking during LNG bunkering operations. Other safety issues include navigational aspects and risk from the passenger traffic.

The ship itself is covered through both the IGC95 Code, the draft IGF Code, ICS rules and guidelines from classification societies. The draft IGF code contains some issues related to ship to ship bunkering. However, as it has not yet been finalized. Hence, this is more specifically the largest gap in rules and regulations concerning the LNG small scale industry.

The SIGTTO document Guidelines on Ship to Ship bunkering covers most of the issues including pre-notification and safety zones. These guidelines are not yet global, though the intent of the guidelines is for authorities and other organizations to use them as input to regulation and guideline work concerning LNG bunkering.

Developing guidance for systems and installations for supply of LNG as fuel to ships is an on-going ISO project. When finalized, these guidelines will constitute uniform standards on some of these issues. Only Norway has some work linked to safety when bunkering with passengers on board. The SIGTTO Guidelines on Ship to Ship bunkering has been developed with these issues in mind. The development, and testing, of the Ship to Ship equipment and procedures need to focus on ensuring the highest degree of safety and reliability.

For Ship to Shore bunkering the draft IGF code is applicable although it has to be further developed towards small scale LNG. The SIGTTO guidelines of the industry best practice for ship-shore LNG handling have been developed with large to huge LNG carriers in mind. ISO 28460:2010 contains numerous provisions in relation to this field. But this standard is not specifically for gas fuelled ships so they cannot be assumed to be either uniform or global in this respect. However, it can serve as a good basis for such a development. This standard targets large scale LNG handling and will not always be applicable to small LNG tankers either.

WP 2.5 – Fuel prices and quality

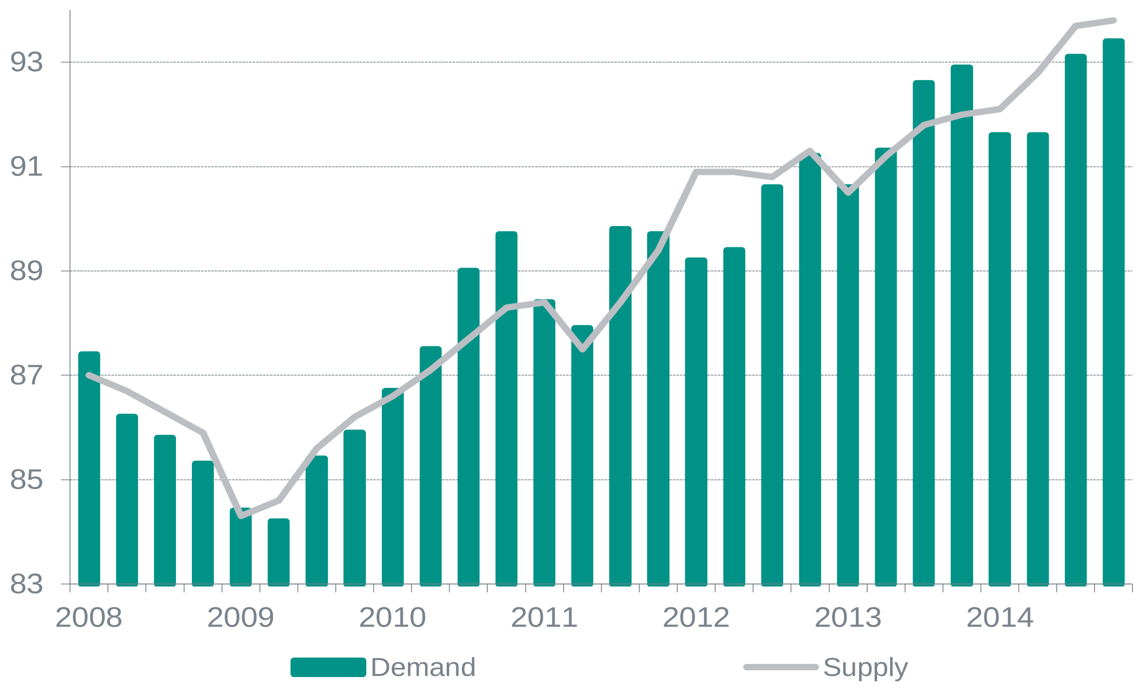
2.5.1. Fuel prices

Fuel prices are an important factor for the feasibility of LNG applications on ships. This raises the question whether the volatile prices for gasoil and/or heavy fuel oil are most important or the spread between the gasoil and heavy fuel oil price on the one hand and the LNG / natural gas price on the other hand. There are no published national tariffs yet for LNG. Presently the landing prices of LNG at the terminal of Zeebrugge provide a valuable source of information. Wagenborg has acted as project leader for the work package on fuel prices, VIV for the work package on fuel quality.

Last year we have seen that there was a large demand for LNG in Asia, and Japan in particular. Due to the shut-down of Japans' nuclear facilities there was a huge demand for LNG in order to maintain the energy demand in Japan. Currently however Japan decided to restart some of their nuclear installations which caused the LNG demand for Japan to decrease. Therefore we can see that the amount of LNG worldwide available is increasing which will have a long term effect of decreasing prices.

The benefit to start using LNG as fuel for operators will only emerge if the gap between LNG and MGO is at a certain level. The increased cost for the LNG installation on board of a vessel compared to the diesel installation need to be compensated by lower fuel prices in order to make the business case sound.

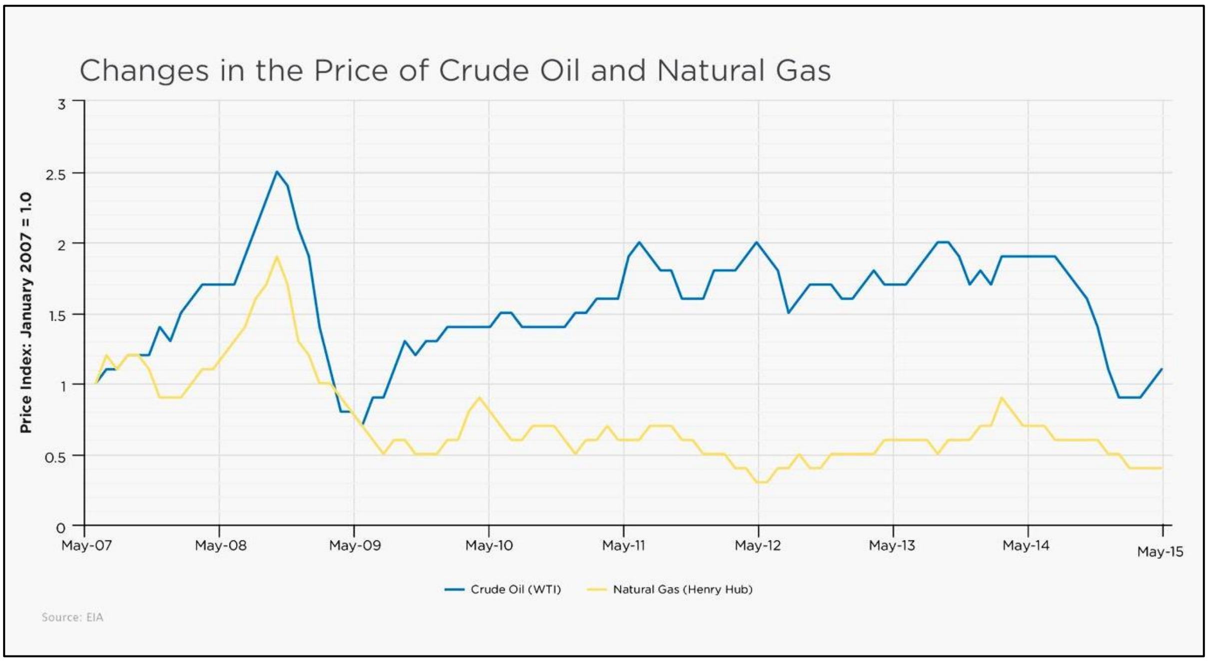
Where we can see that the price of LNG over the past year was rather stable the price for MGO was not. The unstable price for MGO was mainly caused by an oversupply that has been occurring since 2012, as can be seen in Graph 2-5-1.



Graph 2-5-1 Oil prices demand and supply

This overcapacity caused the crude oil prices to tumble to a historic low level. The cause for the overcapacity is obviously the staggering economy that became a worldwide phenomenon in 2012 when even China had to trim down its economic growth. The rebalancing of the China economy shows that 7% growth will be the new norm. Predictions on oil prices for the far or even the near future are difficult to make. For the longer period however expectation is that the oil price will recuperate to around 80 US Dollar per barrel. (See add. WP 2.5.1)

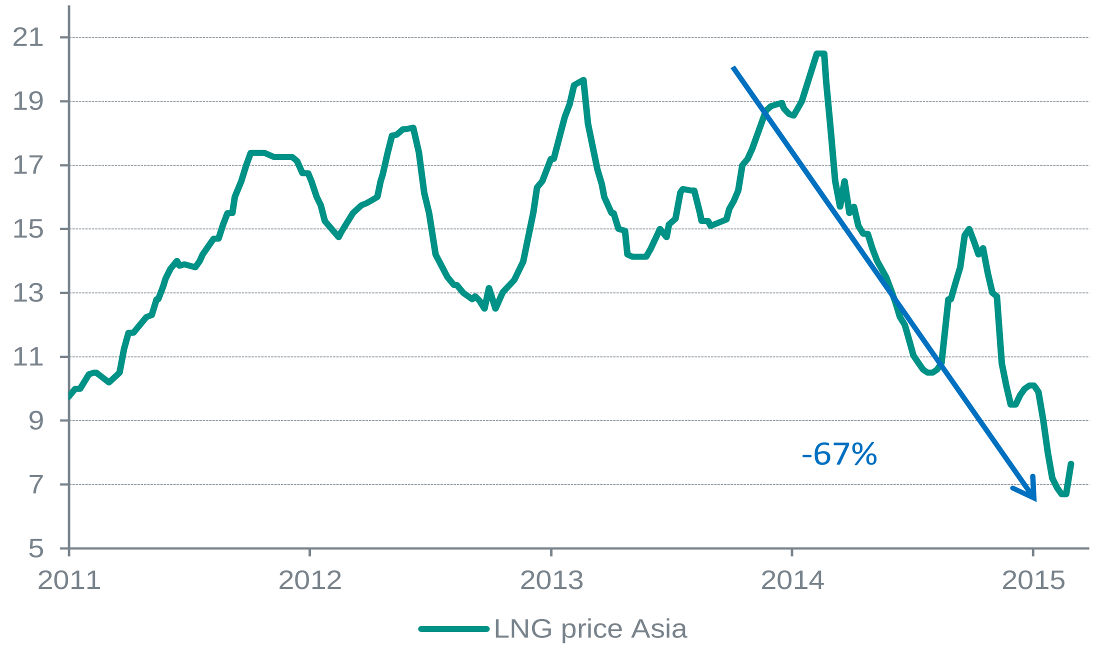
In the midst of the changing oil prices the price for LNG has remained rather stable as can be seen in Graph 2-5-2.



Graph 2-5-2 Oil prices versus Natural gas

Based on the rapidly decreasing demand from Asia on LNG it is expected to see a drop in the European price of LNG in the near future. If we combine this with the expectation that the oil price will stabilize at around 80 US Dollar per barrel, the price gap between MGO and LNG will be expected to remain at the 2012 – 2013 level.

Source: Thomson Reuters



Graph 2-5-3 Sharp drop in LNG prices in Asia since 2014

A subject that has not been investigated in this project is the price difference between LNG and CNG. During the project we have thoroughly investigated the possibility of using LNG as fuel for ships that need to be re-engined and new build. The cost however for a CNG installation on board of a ship is significantly lower due to less expensive tank installations. The amount of fuel that can be bunkered will in terms of kilo's be less than LNG, but it is thinkable that vessels that need only a limited radius can utilize CNG over LNG. The earn back time for such a vessel will be easier to obtain.

For a future project it might be interesting to investigate if a cost model can be made to determine if for those vessels a shorter earn back time can be achieved when using CNG.

2.5.2 Fuel quality

The variation in LNG composition can adversely affect engine performance. These effects can include misfire, stumble and underrated operation as well as engine knock and overheating. These effects are dependent on the engine's ability to tolerate or compensate for the variation in fuel composition. The resistance to knock is called the fuel methane number. This number runs from 0 (no knock resistance) to 100 (very high knock resistance) and more.

The methane number is a measure of the knock resistance of the fuel. Knock can be extremely damaging to an engine. The knock resistance of the fuel is a function of the fuel composition. Methane has a very high knock resistance. The heavier hydrocarbons in LNG, such as ethane, propane, and butane, have lower knock resistance and thus reduce the overall knock resistance of the fuel. LNG with a methane number lower than 70 is generally not acceptable for spark ignited or dual-fuel engines. In the table below you can find the methane number per LNG producing country. (see add. WP 2.5.2)

Gas composition	Symbol	Unit	Russian Group H	North Sea Group H	Danish Group H	Libya LNG (rich)	Nigeria LNG (mean)	Egypt LNG (lean)	Biomethane	Biomethane +LPG
methane	CH_4	mol%	96,96	88,71	90,07	81,57	91,28	97,70	96,15	90,94
nitrogen	N_2	mol%	0,86	0,82	0,28	0,69	0,08	0,08	0,75	0,69
carbon dioxide	CO_2	mol%	0,18	1,94	0,60				2,90	2,68
ethane	C_2H_6	mol%	1,37	6,93	5,68	13,38	4,62	1,80		
propane	C_3H_8	mol%	0,45	1,25	2,19	3,67	2,62	0,22		5,00
n-butane	n-C_4H_{10}	mol%	0,15	0,28	0,90	0,69	1,40	0,20		0,50
n-pentane	n-C_5H_{12}	mol%	0,02	0,05	0,22					
n-hexane	n-C_6H_{14}	mol%	0,01	0,02	0,06					
hydrogen	H_2	mol%								
oxygen	O_2	mol%							0,20	0,19
total		mol%	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
superior calorific value	H_{sv}	MJ/m^3	40,3	41,9	43,7	46,4	44,0	40,7	38,3	41,9
superior calorific value	H_{sv}	kWh/m^3	11,2	11,6	12,1	12,9	12,2	11,3	10,6	11,6
relative density	d	-	0,574	0,629	0,630	0,669	0,624	0,569	0,587	0,641
Wobbe index	W_s	MJ/m^3	53,1	52,9	55,0	56,7	55,7	53,9	50,0	52,3
Wobbe index	W_s	kWh/m^3	14,8	14,7	15,3	15,8	15,5	15,0	13,9	14,5
methane number	MZ	-	92	79	73	65	71	92	103	77

Graph 2-5-4 LNG Fuel quality from different regions

The methane number of LNG determines the quality of the engine performance and therefore the emissions. In line with international standards for HFO, MGO, diesel and petrol, national and international standards should be developed for different grades of LNG. The methane number of LNG can be a good guideline for this.

WP3 – Business cases for Short Sea Shipping

A framework for the business cases is drawn up containing the following elements: selection of generic ship and operational sailing profiles and relevant requirements regarding availability of LNG. Also a selection of technical options for loading, storing and distribution and an assessment of economic feasibility and implications for the LNG infrastructure and distribution is made. Finally a selection of technical options for loading, storing, distribution, gasifying and propulsion system and an assessment of the economic feasibility for LNG on board of short sea ships is made.

WP 3.1 LNG storage systems

Designing pressure vessels requires complex calculations that fall beyond the scope of this project. However different tanks configurations, shapes and materials were evaluated in order to make optimal use of limited cargo space on board short sea ships. Based on existing examples from practice other options were studied as well.

The storage tank for LNG on the vessel is an area of concern for the ship-owners for many reasons. LNG requires about twice as much volume to provide the same energy as HFO. In addition, the tanks in use today for LNG fuelled vessel are additionally space requiring and also add extra weight.

There are three types of tanks that could be a possibility for LNG fuelled vessels. In addition the membrane tank could be an alternative. This type of tank is today used for LNG carriers but not currently allowed for LNG fuelled vessels. Current application of LNG as transport fuel for ships all have IMO C type tanks installed. The various tanks concepts all have their pros and cons and different segment in the shipping industry have different characteristics that will lead to tank choices based on space availability, sailing profile etc. (see add. WP 3.1)

A pressure vessel made of a metal liner with a mantle of carbon fibre reinforced plastic (CFRP) can be an attractive alternative. The principles and design of the storage systems is examined further in this work package. Cryotek has acted as a project leader for this work package.

Introduction

Natural gas is a natural fuel containing no sulphur, virtually no soot when released, very low NO_x level and also gives a strong reduction of CO_2. Natural gas, however, is bad to transport as gas because it requires a large storage capacity. The conversion from natural gas to LNG gives a reduction of 600:1 in volume at a low temperature of -163^{0}C for storage. As a result we see cylinder shaped, insulated storage tanks that can be placed on deck or below decks. Before LNG can be used as a fuel, it should again be made gaseous and on the right pressure and temperature before it can be burned in a diesel engine. This has its implications on all the equipment on board.

Cryotek is active in this market on the basis of extensive research among potential users and suppliers. They have ample experience with LNG storage systems and contacts with several shipping companies in France, UK, Norway, Netherlands, England, Japan, Greece and in the Caribbean.

Existing market parties in the sale and distribution of oil, and fuels such as LPG, are expected to take the lead in the new market for small scale LNG. They have the knowledge of distribution, regulations for dangerous substances and trade in these fuels.

Gas-treatment and arrangement

Cryotek has focused on the aspects of the treatment and storage of liquid gas and the associated measurement and control techniques. Aspects such as using natural gas as fuel for the propulsion of the ship, smoothing of the boil-off gas to LNG, custody transfer systems on board and transfer systems of ship-to-ship play a major role. The input of information is not limited to that obtained in the time frame of this project. Information which has already been gained over the past years was also used in this project.

Natural gas as fuel for propulsion

The fuel for the propulsion of these ships is gas or a mixture of diesel/gas (dual fuel engines). The applicable laws and regulations were reviewed, as well as available technologies for LNG storage. This has led to a so-called Process & Instrumentation Diagram (P & ID). From this P & ID analyses were made of the various components such as LNG tanks, pumps, evaporators, valves, instruments, etc.

As a result of these activity a General Arrangement (GA) drawing is produced showing the LNG storage tank and the so-called cold room. This is a defined space where all the cold room equipment for pumping and vaporization of LNG is mounted as well as all instruments and valves to regulate the natural gas pressure and temperature to the propulsion engines.

Smoothing of boil-off gas on board

Despite the good insulation of the LNG storage tanks there will be heat leaks, warming up the LNG. Depending on the pressure a part of the LNG will become natural gas of low temperatures of approximately -160 ^{o}C. This gas can be used as fuel for the engines but, especially if there is no consumption (e.g. the ship is in port) there will be a solution to this system of boil-off gas.

The existing plants are designed for the large LNG ships (such as type Q-max LNG carrier) and are to big, to complex and to expensive for short sea shipping application. After a thorough study a choice was made for so-called cryogenic regenerators. Depending on the boil-off rate a number of these units will condense the cold gas in order to keep pressure and temperature of the LNG constant.

Furthermore, these (specifically in the Netherlands developed) "reliquefaction units" provide new possibilities for transport and storage under different pressures. For short sea shipping, this gives extra opportunities, since it increases the operational possibilities for customers who can not or do not want to receive LNG at a pressure above 1 bar. Cryonorm has developed a special unit that is available for installation on board short sea ships.

Custody transfer

The development of a so-called "custody transfer system" (measurement of the quantity and composition) of the delivered LNG for installation aboard ships to the delivered quantity and quality "real time" is an important issue. To determine what is delivered to a recipient, the quantity (by weight) and the calorific value of the delivered LNG can be adopted during the handling.

Measuring systems with simultaneous determination of specific weight give an insight in the weight of the delivered gas. If measured on the gas return manual and any pipeline to the engine room for consumption of gas on board, it can be calculated how much gas to the recipient is really delivered.

To determine the calorific value a sample is taken on board and its composition is analysed in a gas chromatograph. If the samples are taken at different times, a picture of chemical composition and calorific value can be established and recorded. Of course this is important at checkout after the transfer.

LNG transhipment systems

A comprehensive study of the possible and available transfer systems of "shore-to ship", "ship-to-ship" and of the "ship-to-shore" was made. A special challenge is the transhipment between two ships at sea in which the condition of the sea and the wind can greatly determine what the operational envelope is within which transfer still can take place safely.

Special hydraulic loading arms with fixed mains and cryogenic, gas-tight hinge points form the basis for most concepts. Gas return and the ability to immediately stop in emergencies (Emergency Shut Down – ESD) and quickly and safely loosening the loading arms present a challenge because of the small scale in relation to the existing systems on shore at the large LNG export terminals.

Developed LNG Tankers

A 4.000 m^3 LNG bunker tanker design was developed based on the first insights. In the following conversations several stakeholders indicated the need for a slightly larger bunker vessel, which resulted in a 5.200 m^3 LNG version.

It has been found, that there is a great need for new "short-sea" LNG tankers. However, there is a great hesitation with regard to "the-chicken-and-egg" situation for LNG bunkering requirements. There is interest for LNG as a transport fuel but there is still no adequate delivery possible on the one hand. On the other hand, there is serious interest to invest in LNG supply, but there is still insufficient demand to justify the investment.

Developed LNG Barges

Recently a few Norwegian parties discussed on the possibility of cheaper and flexible solution for small and sometimes marginal supply situations in remote or developing areas and markets. The discussion resulted in a set of bunker barge concepts with different LNG tank capacities.

Big advantage is, of course, the lower amount of investment and with still a flexible and mobile LNG bunker barge. The barge can be towed with a tug to the bunker station. All requirements with regard to LNG storage, safety and security can be met and there is no permanent crew on board. Monitoring can be done via wireless communication to a shore station and the bunkering can be carried out by the ships crew. New procedures for LNG bunkering in this manner still have to be developed.

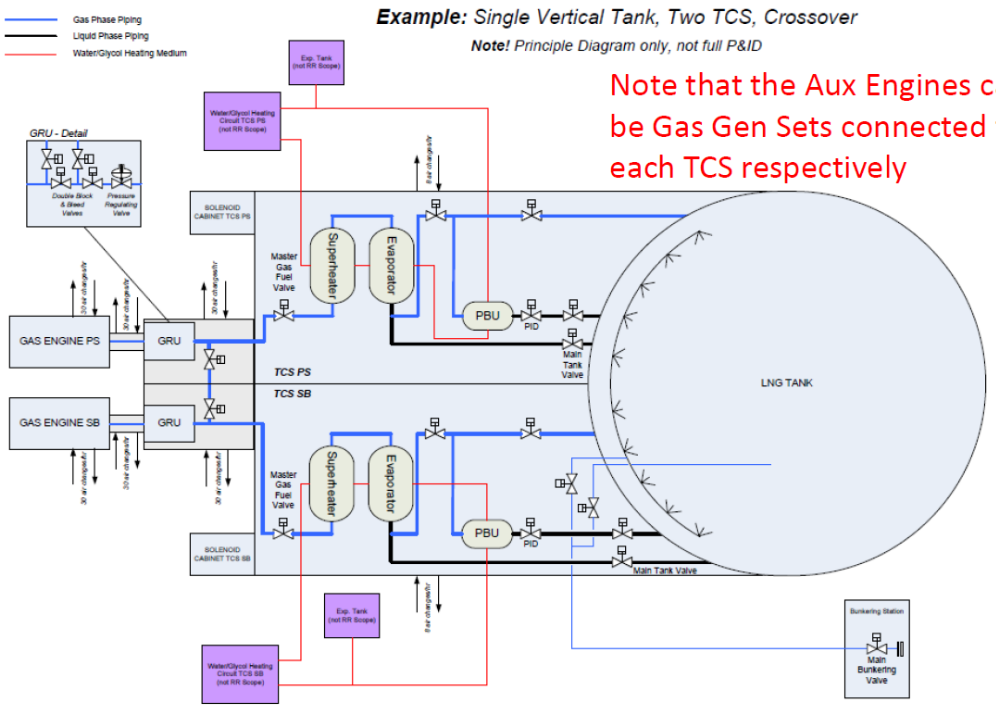
To do this, the customers already have a network of LNG land based systems for various applications such as electricity generation, heat production, energy for local factories, supplying ships and refuelling for land transport. This land based systems are now supplied via the "Pioneer Knutsen" or tank trucks from one of the LNG production facilities in Norway.

Barges of 1.000, 2.000 and 2.800 m^3 are already developed. The 1.000 m^3 version is currently in the stage of decision with one of the "Naturgass" organizations. Behind these organizations, regional energy companies are usually active through a cooperative. Various interested parties are currently interested in this concept, especially in the Caribbean, Norway and the Baltic States.

Prospects and future developments

it is expected that in 2015 and 2016 the several variants of the LNG tanker will be developed further. Currently there are about ten projects for various LNG tankers including two for the variant without own propulsion and without accommodation. Both types are interesting and provide access to a different part of the market. As from 2015/2016 the requirements for emission of exhaust gases will take into effect and the capabilities of LNG will all become clearer. The decision of a few large stakeholders in the LNG supply chain market to invest in a bunker tanker will give a huge boost.

At the moment the absence of clear prices for LNG delivered on board is a significant hindrance to the introduction of LNG for short sea shipping. However the insight of many indicates, that there is a part of the market that is ready for LNG and especially in the SECA areas where the benefits are most clearly. A number of large ferries in Norway and Sweden and the Canal will turn to LNG as a transport fuel and have found solutions for the bunkering infrastructure. Some solutions are clearly temporary and ask for a final solution where a new build bunker ship is a possibility. Proprietary loading and unloading systems with associated measurement and control systems will become an important key to success. (see add. WP 3.1)



Graph 3-1-1 Example of vertical LNG tank system

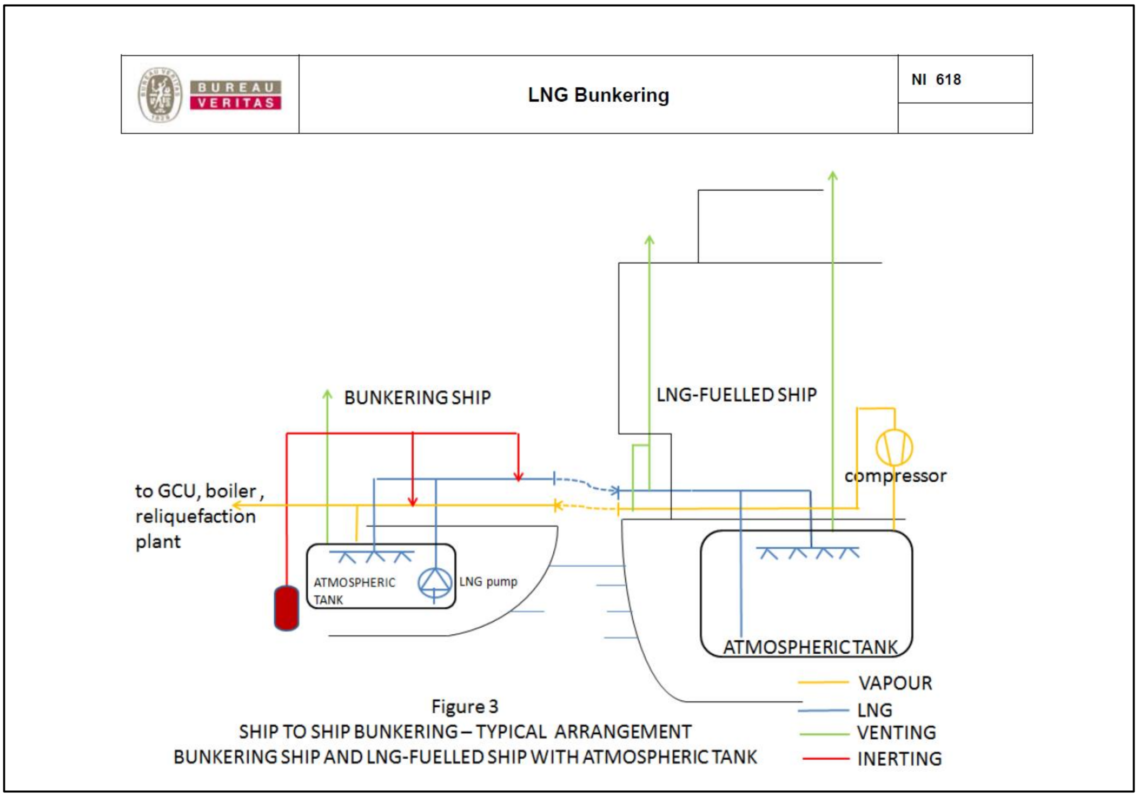
WP 3.2 – LNG bunkering procedures

The work package provides solutions for a fuel supply system including loading LNG as well as bunkering couplings, purging systems, safe and environmental friendly unloading of LNG and the implications of these systems on the design and lay-out of the short sea ship and the overall system costs .

LNG terminals with regional distribution of LNG by trucks are equipped with facilities for loading and unloading of trucks. Flexible hoses are used for the transfer of LNG between the truck and the terminal. The truck can carry between 40 to 80 m3 of LNG depending on allowable size of trucks in a specific country. A normal bunkering operation from a semi-trailer takes up to two hours including signing of documents and safety procedures. The pumping time is approximately one hour.

For transfer of LNG between the storage and the vessel, insulated piping with a pipe connection or marine loading arm is used. The same pipeline is used for the supply of LNG from a LNG carrier to the terminal and the bunkering of vessel from the terminal. The distance between the terminal and the quay should be as short as possible to minimize boil-off. Boil-off vapours from the onshore LNG storage tank are displaced via the vapour return line to the LNG carrier. Furthermore, most of the LNG terminals should be equipped with a filling station for LNG road trucks and for regional distribution of LNG to maritime customers.

Recommendations for bunkering procedures are described in detail by the classification societies Bureau Veritas (BV) and Det Norske Veritas (DNV) (see add. WP 3.2). Other recommendations, guidelines and requirements are already described in previous work packages. (see add. WP 2.3 and WP 2.4)



Graph 3-2-1 Ship tot ship bunkering arrangement

WP 3.3 – Gas engines, dual fuel engines and engine conversion

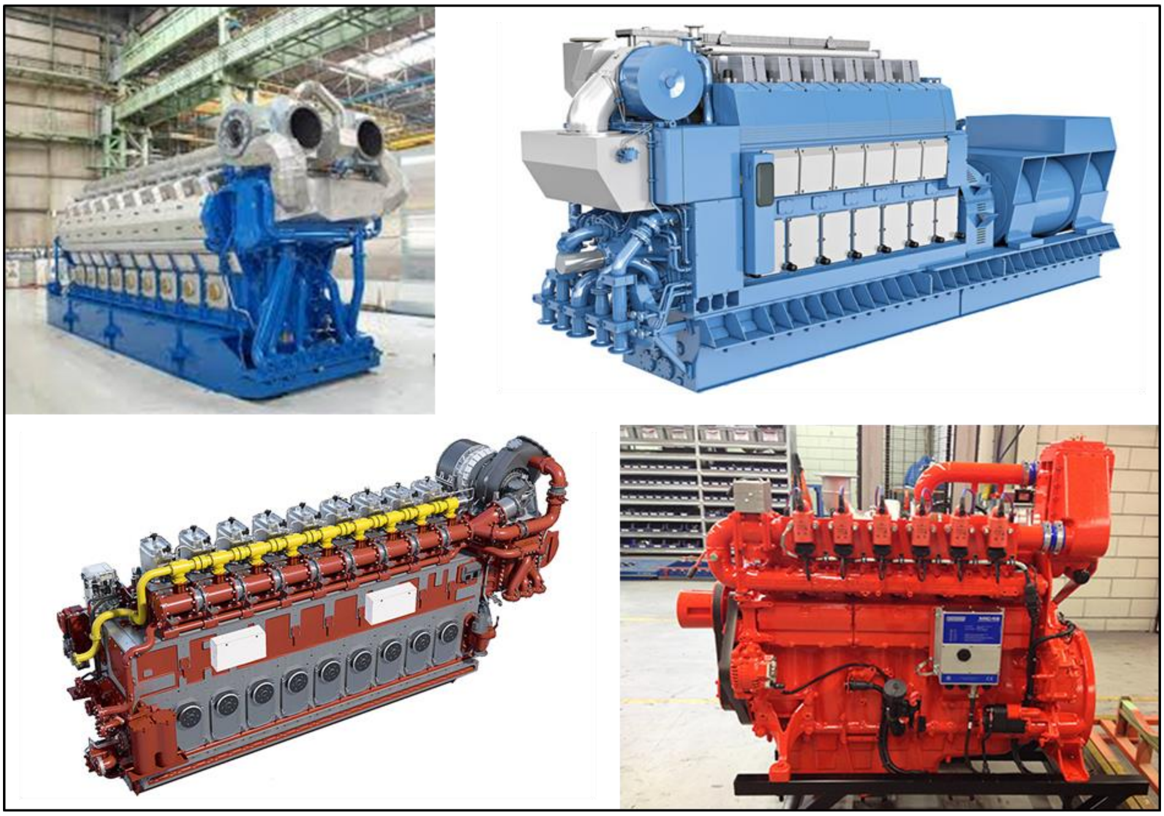
There are several gas engines and dual fuel engines on the market that can be applied on short sea ships. For the business case of the conversion of existing short sea ships it is also important to determine whether existing engines on board can be modified.

This can be an important advantage for profitability of existing short sea ships. The work package examines the development of these modifications and establish the technical and financial implications. The work package leader is Wartsila Netherlands.

Medium and heavy-duty gas engines are usually designed as lean-burn engines, because these engines are more fuel-efficient and produce lower combustion temperatures. This engine technology is used to meet applicable exhaust emission standards without the use of after-treatment technology. Excess air both ensures that all the fuel is burned and dilutes the combustion products to reduce the combustion gas temperature. The lower combustion temperatures minimize NOx emissions without after-treatment as well as increase hardware life.

Lean-burn engines are more susceptible to problems arising from variable fuel quality. Most lean-burn heavy-duty engines are designed to operate close to the lean mis-fire zone to minimize NOx emissions. Changes in fuel quality for a lean burn engine can result in mis-fire if the change results in leaner conditions, or detonation and/or overheating if the change results in richer conditions.

The technical specifications and emissions characteristics of the various gas and dual fuel engines of Pon Power (Caterpillar and MaK), Rolls Royce, Sandfirden Technics and Wartsila are described in detail in the documents in addendum 3.3 (see add. WP 3.3)



Graph 3-3-1 Several gas engine solutions from different manufacturers

WP4 – System design for Short Sea Shipping

The market-segment of shipping that is known as "Short Sea Shipping" relate to ships that primarily operate in coastal trades. There is a wide diversity of ships operating in it, with mutual differences in type, size, speed, operational pattern, propulsion system, etcetera. These vessels include general cargo vessels, tankers, container vessels, passenger vessels and offshore supply vessels. A number of ships that periodically sail in short sea shipping trades are shown below. Based on a number of design considerations, such as space issues for placing the LNG tank, LNG is likely a more suitable fuel for some of the ships than for others. Conoship has acted as leader of this work package.

Graph 4-1 Ship types evaluated in detail for LNG solutions

The objective of this chapter is to explore the design challenges related to utilizing LNG as a fuel for short sea ships. The research work includes:

- identifying the design aspects that determine the feasibility of LNG as a fuel for ships;
- identifying the suitable LNG lay-outs and components for different types of ships;
- getting a better understanding of the way LNG regulations affect the LNG system design.

The exploration of the design challenges is based on the conceptual system designs of four ships ('cases') that operate (periodically) in North European SECA's. Each case is worked out by the dedicated 'case-owner' (Damen, Meyer Werft, Conoship and Wagenborg) in cooperation with the project participants. The vessels, which were selected from a long list, are:

- Damen: Damen Offshore Carrier 7500;
- Meyer Werft: comparison of a ferry (retrofit) with a new to build bunker barge;
- Conoship: Wagenborg's E-borg;
- Wagenborg's Oranjeborg.

Paragraph 4.1 describes the results for the analysis of Damen's Offshore Carrier 7500, followed by a description of the Meyer Werft's (retrofit) ferry design and a new to build LNG bunker barge. The results of the analysis of Wagenborg's E-borg is presented in paragraph 4.3. Paragraph 4.4 describes the Oranjeborg case. The general findings are summarized in paragraph 4.5.

4.1 Damen case - Damen Offshore Carrier 7500

Damen shipyards Bergum entered the project with the standard “Damen Offshore Carrier 7500”. This ship type is specifically designed as a smaller heavy transport, offshore installation and ro-ro platform suitable for multiple markets and tasks. The Damen Offshore Carrier aims to provide flexibility and year-round utilization.

Since it is a ship type with a typical operating profile inside the ECA, it is good to assess if LNG is an economical interesting alternative fuel. Also the diesel electric propulsion and standard DP2 makes this an interesting business case.

Graph 4-1-1 Damen Offshore Carrier 7500

Principal dimensions

Length over all	119,08 m
Breadth moulded	27,45 m
Depth to upper deck	9,00 m
Draught design approx.	5,45 m
Deadweight at design draught.	7.300 ton
Draught scantling approx.	5,80 m
Deadweight at scantling draught	approx. 8.300 ton
Gross Tonnage	approx. 8.242 GT
Main engine power	3.900 kW
Trial Speed at design draught,	approx. 12,5 kts
Operating area:	European SECA

Classification

Gas storage tanks, piping and equipment will meet: IMO interim guidelines on safety for natural gas-fuelled engine installations in ship [MSC.285(86)]. And the classification rules of: Lloyd's Register - Rules and regulations for the classification of natural gas fuelled ships [July 2012]. When the IGF Code does enter into force, it will revoke the above mentioned IGF Interim Guideline. Although earliest possible entry-into-force date for the IGF Code is now July 2017, it could not be used for this business case.

Electrical system of a standard DOC7500

DOC 7500 Standard Cofiguration

Eng. Type	*2x MaK 6M25C*	*2x MaK 8M25*
Power:	1824 [kWe]	2560 [kWe]
Specific fuel oil consumption:		
100%	186 [g/kWh]	187 [g/kWh]
85%	184 [g/kWh]	184 [g/kWh]
75%	185 [g/kWh]	183 [g/kWh]
50%	193 [g/kWh]	195 [g/kWh]

Graph 4-1-2- DOC 7500 standard configuration

Configuration on LNG

DOC 7500 LNG Cofiguration

Eng. Type	*2x Mak 6M34DF*		*2x Cat G3516C*	
Power:	2870 [kWe]		1550 [kWe]	
Specific fuel oil consumption Diesel/Gas:				
100%	188 [g/kWh]	7665 [kJ/kWh]	- [g/kWh]	9290 [kJ/kWh]
85%	187 [g/kWh]	7777 [kJ/kWh]	- [g/kWh]	9375 [kJ/kWh]
75%	187 [g/kWh]	7854 [kJ/kWh]	- [g/kWh]	9460 [kJ/kWh]
50%	193 [g/kWh]	8286 [kJ/kWh]	- [g/kWh]	9960 [kJ/kWh]

Graph 4-1-3 DOC 7500 LNG configuration

This configuration was developed in cooperation with one of the project partners, Pon Power. Two medium speed engines are selected which will be used during transfer, when a constant amount of power is needed. During DP operations, power demand is fluctuating and the high speed engines are fully capable to handle these fluctuations. In addition, most of the time the power demand on DP operations will not be that high. The small engines will reduce fuel consumption.

Tank size

For autonomy of 14 days, 40% of time transfer and 60% DP operations, the required LNG capacity is approximately 450 m^3. Because only 75% of an LNG tank can be used effectively, the required tank capacity is approximately 600 m^3.

Tank system

The LNG tank system consists of an IMO type C stainless steel tank with submerged centrifugal pump and pressure control system. The gas pressure in this system is created by a centrifugal pump. This maintains a constant pressure to the main engines without an increase of fuel temperature inside the tank. Although this system results in a slightly higher energy consumption, it also makes sure that the engines are continuously running on gas and not switch over to gasoil in case of a pressure drop.

Tank location

Best tank location is a void space under main deck near the engine room. Two tanks can be located side by side without modification of the main frame construction. By placing the tanks under deck the complete deck length stays the same, which is very important for this type of ship. Short piping length to the ER is another benefit of this location.

Engine room configuration

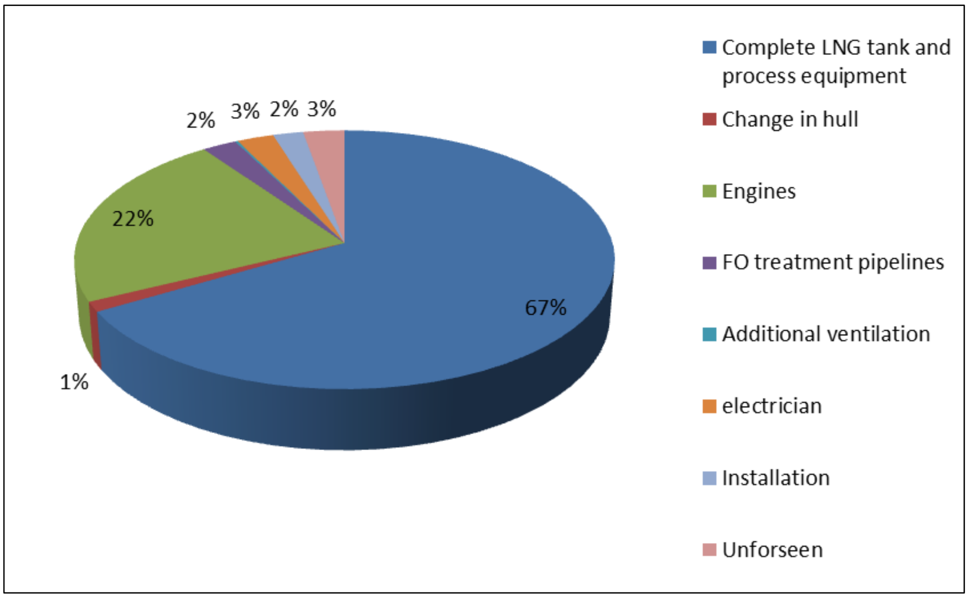
Two alternative system configurations may be accepted:
- *Gas safe machinery spaces;*
- *ESD-protected machinery spaces;*

To keep the system as simple as possible it is recommended to create a gas safe machinery space. In this case the gas valve units and the caterpillar engines have been moved to a separate ventilated space.

Findings of the case and solutions of the design challenges

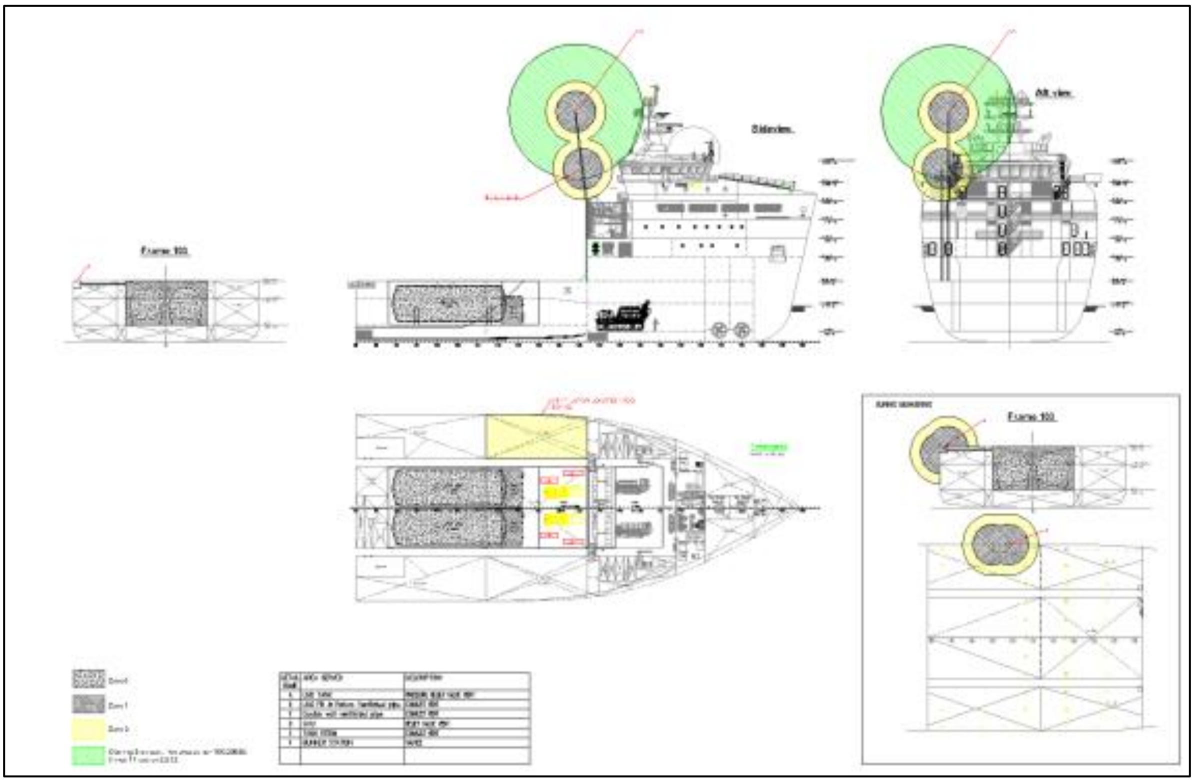
From a technical point of view there will be no obstacles for the introduction of LNG as fuel for a DOC 7500. The most expensive part of the installation will be the LNG tank + tank equipment itself. Using LNG as fuel as an alternative to GO or HFO will be more viable when this tank installation become cheaper. Standardization and/or mass production will inevitable reduce the production costs.

Because of the expensive tank installation it seems to be hard to design a standard installation without knowing the exact operating profile. By combining LNG and MGO it could possibly be a replacement for HFO. In that case there is no need for a LNG tank that fits exactly in an operating profile and a standardized tank becomes more in sight.



Graph 4-1-4 Additional costs LNG system DOC 7500

Due to the current investment costs versus the current fuel prices, LNG as fuel is commercially no feasible solution for a DOC7500. At current fuel prices there will not be a break-even-point in a reasonable time. Therefore it will be necessary for LNG in the future get a fixed price difference compared to MGO. And investment costs of a LNG installation have to reduce at least by half. (see add. WP 4.1)



Graph 4-1-5: Hazardous area plan of the DOC7500

4.2 Meyer Werft case - Pont Aven (ferry) and bunker barge

The specialized vessels designed by Meyer Werft are quite difficult ship types with regard to a retrofitting. For example, on a cruise vessel the limited space in the technical area below the hotel will not allow the storage of LNG in a tank hold space. Placing the tank in the upper hotel area will cost a lot of cabins which makes a retrofit economical unattractive.

- A retrofit project: ferry "Pont Aven";
- A new to build vessel: bunker barge.

Therefore, Meyer Werft has analysed two cases.

4.2.1 Retrofit project ferry "Pont Aven"

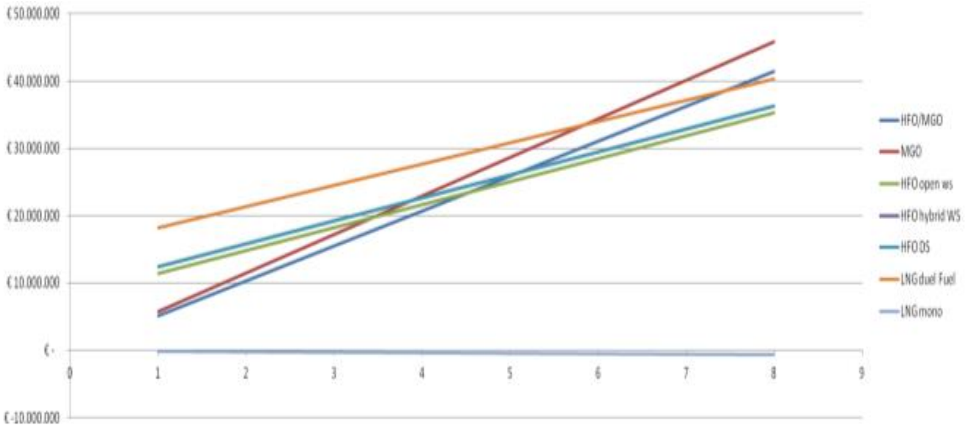
The ferry "Pont Aven" was delivered in March 2004. Ferries of similar design are operating inside the ECA of North and Baltic Sea. The ferry has 4 engines MAK Type 12V M43, total Power is 50,4 MW. Today the HFO Bunker capacity is 995 m³. A conversion to LNG would require about 1650 m³ LNG bunker.

Principal dimensions

Length over all	184,30 m
Length between pp	170,80 m
Breadth moulded	30,90 m
Depth to upper deck	9,70 m
Draught design approx.	6,80 m
Capacity	2.415 passengers, 600 vehiles
Gross Tonnage	41.700 GT
Main Engines	50.400 kW - 4x MaK 12V M43
Cruising speed	27 kts
Operating area:	European SECA

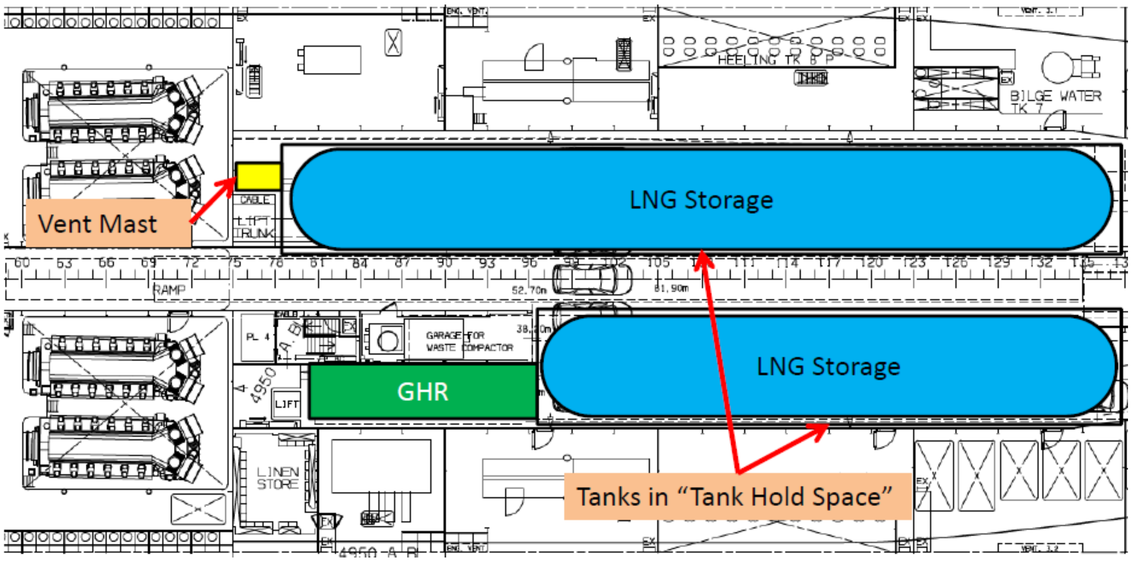
Graph 4-2-1 Pont Aven retrofit

The only space which could be used to put the LNG Tank on board is on Deck01 and Deck 02. The size of the LNG tank which has to be placed in a gastight Tank hold space will affect the lower Car deck capacity. The energy storage on board needs a reduction by about 20% when converting to LNG. This is because of the restricted length which is available to place the LNG Tank within B/5. It was found that the overall cost for such conversion were estimated to about 15 Mio Euros. 4 x converted motor, plus tanks with gas handling, bunker station vent mast and control equipment. Due to the high investment and losses in capacity, a conversion seems to be not feasible for such ship.

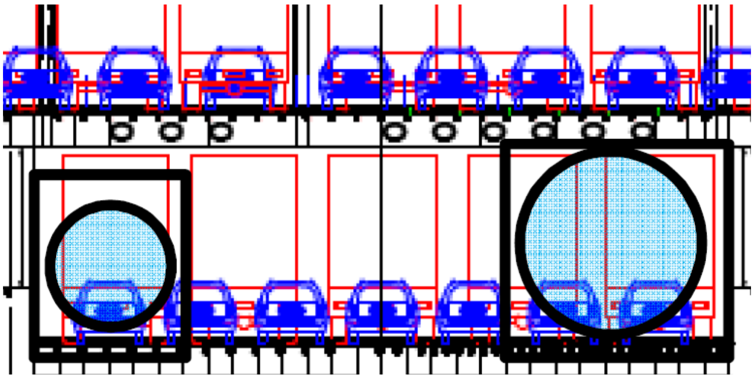


Graph 4-2-2 Impact of the high investment on the pay-out period.

To conclude, the investment costs are far too high to consider the retrofit project viable.



Graph 4-2-3 Indication of the limited space on board a ferry.



Graph 4-2-4 Indication of the lost car deck space due to LNG tanks.

4.2.2 New to build case LNG bunker barge

Principal dimensions

Length over all	104,00 m
Breadth moulded	18,40 m
Draught design approx.	5,00 m
Gross Tonnage	5.600 GT
Bunker capacity	5.000 m3 LNG
Engines	3x 1.060 kW
Service speed	13 kts
Operating area:	European SECA

Graph 4-2-5 LNG Bunker barge with Dual Fuel engine.

Comparing the cost of the DF engine installation and a conventional HFO engine installation result in only slightly higher investment of the LNG installation. Many auxiliary systems which are required to heat and prepare the HFO are eliminated and no additional LNG tank is necessary for the propulsion because the boil-off of the gases are used. It can be reported that a ship operating in an ECA area only is today more economical in using LNG for propulsion than a conventional design which requires a scrubber and later on an SCR, leading to higher investment and operational cost for chemicals, personnel and maintenance.

4.3 Conoship case - Elbeborg (multi purpose)

Wagenborg's 'Elbeborg-class' are typical multi purpose vessels, with two large box-shaped holds for the efficient carriage of containers as well as nearly all other types of general cargo. This vessel operates periodically in the European SECA as well as in the North-American SECA. Some of the characteristics of the vessel are shown below.

Principal dimensions

Length over all	144,56 m
Breadth moulded	15,87 m
Draught design approx.	8,00 m
Deadweight at design draught.	12.000 ton
Gross Tonnage	7.680 GT
Main engine power	Wärtsilä 9L32C, 4500 kW
Trial Speed at design draught,	approx. 13 kts
Auxiliary power:	1 shaft generator
	2 auxiliary power sets (280 kW)
Operating area:	North American SECA
	Trans-Atlantic
	European SECA

Graph 4-3-1 Elbeborg case

Required LNG capacity

The voyage statistics of 7 E-borgs are analysed in order to discover the share of fuel consumption inside ECA's relative to the total fuel consumption and to determine the required LNG capacity. This analysis showed that an LNG tank with a geometrical volume of 200 m^3 is required.

System lay-out

The conceptual design of the LNG system is the result of a number of design considerations. The LNG system consists of the following components:

Dual fuel engine. A dual fuel engine is preferred to a gas-only engine because of the ability of DF engines to switch to HFO when operating outside ECA's. The benefit of this decision is a limited tank size and thus lower investment costs and a lower impact on cargo carrying capacity. Another benefit: fuel flexibility, when LNG bunker facilities are not in place (yet);

LNG Tank. A single IMO Type C stainless steel tank. A single LNG tanks comes with lower investment costs than a double-tank setup. A single cylindrical tank also has the benefit of a higher space (volume) efficient storage, although the dimensions may become unfavourable. A membrane tank is considered not viable, due to the high investment costs in relation with the relatively low required LNG capacity.

LNG tank positions

A cylindrical LNG tank can be allocated in various positions and in different orientations: longitudinal orientated, transversal orientated and vertical orientated. Each position of the tank have a number of pros and cons. The investigated tank positions, and their specific pros and cons, are described below.

Position	Pros	Cons
Hold 1, front side, vertical	- Stability: relatively low VCG; - Sufficient space for single tank; - No impact on GT;	- Long piping length required; - Impact on hold volume; - Adverse contribution to bending moments in ballast condition;
Cross-section, vertical	- Stability: relatively low VCG; - No impact on hold volume; - Small increase of the section length results in increased DWT; - No impact on GT;	- Limited height in relation to height of the hatch-cradle; - LNG tank on the cost of IFO 380 bunker capacity;
Hold 2, aft side, vertical	- Stability: relatively low VCG; - Short piping length; - Sufficient space for single tank; - No impact on GT;	- Impact on hold volume; - Adverse contribution to bending moments in ballast condition; - Limited height in relation to height of the hatch-cradle;
On poopdeck, longitudinal	- No impact on hold volume; - Short piping length.	- Impact on GT; - Adverse contribution to bending moments in ballast condition; - Stability: relatively high VCG;

Graph 4-3-2 LNG tank positions

Based on this analysis, two positions were worked out in detail: the LNG tank placed in the cross-section and the tank positioned on the poopdeck.

Findings of the case

The exploration of the design challenges related to the conceptual LNG system design of the Elbeborg resulted in the following findings:

There are hardly any hurdles, from a technology point of view, that prevent the introduction of LNG as a fuel for ships such as the Elbeborg;

The tank size, which is related to the operational profile, should be carefully considered. The tank size (may) have a considerable impact on the investment costs and the impact on the design (bending moments, hold volume, etcetera);

Specifically for the Elbeborg case LNG is currently not a viable alternative for switching to MGO < 0.1% sulphur, due to the combination of the current operational profile (fuel consumption inside/outside ECA's), the current fuel prices and the current investment costs related to LNG systems;

The pay-out period for an LNG system in relation to MGO operation in ECA's is currently 21.9 years, given the current prices of fuel and equipment and the operational profile of the E-borg series.

4.4 Wagenborg case: Oranjeborg (roll on - lift off)

Wagenborg Shipping, a Dutch privately owned shipping company specialized in the transport of dry cargo, owns and operates a fleet of approximately 180 oceangoing vessels with a deadweight of between 6.000 and 23.000 tons, most of which are engaged in Short Sea Shipping. Wagenborg Shipping, being an ISO14000 certified company, continually strives to minimize her environmental footprint, not only by optimizing the entire logistic chain, but also with studies as to which fuel would be preferred.

The project LNG for Short Sea Shipping has delivered valuable insights in the possibilities of LNG as marine fuel for Wagenborg, both for potential newbuilding as well as for retrofitting of existing vessels. The project has also identified a number of issues that need further study and/or development, for example the bunkering procedures. Most importantly, the project has delivered a software tool that enables Wagenborg to quickly analyse a random vessel for different fuel and exhaust gas abatement options.

Within the project, several Wagenborg vessels have been analysed. This has resulted in one particular vessel being found especially suitable for retrofit to LNG, as long as technical aspects only are considered. Main reasons are that this vessel, MV Oranjeborg, has the physical space to install a LNG fuel tank of sufficient size without interrupting cargo operations or hold volume, it's main engines are of a type and size that can either be converted to LNG or replaced by gas engines of similar power. Further, the internal logistics of gas fuel piping within the vessel is expected to be relatively easy. The project partners have visited Oranjeborg to investigate the possibilities and a preliminary design has been made.

Principal dimensions

Length over all	158,84 m
Length bpp	150,75 m
Breadth moulded	25,60 m
Depth	16,30
Draught design approx.	9,00 m
Deadweight at design draught.	15.092 ton
Gross Tonnage	18,289 GT
Main engine power	Wärtsilä 9L32C, 12.600 kW
Trial Speed at design draught,	approx. 18 kts
Operating area:	North American SECA Trans-Atlantic European SECA

Graph 4-4-1 Oranjeborg refit

The biggest challenge for the actual conversion of MV Oranjeborg to LNG is not technical but commercial. This was clearly shown by the LNG for Short Sea Shipping tool. Oranjeborg sails between the Baltic Sea and the North American East coast, and is chartered per voyage. So far, it has not been able to fix a charter for a longer period. The lack of such charter is a serious handicap in finding sufficient funding for the conversion. To minimize the initial investment, a subsidy has been applied for within the Horizon2020 program of the European Commission. Even if this subsidy is granted, a substantial investment by Wagenborg is still necessary which will be difficult, considering the current economic situation the shipping industry finds itself in.

4.5 General findings

This chapter described the results of the exploration of the design challenges related to LNG as a fuel for short sea ships. The ships that were analysed in detail have large differences based on type, size, task, operational profile, etcetera. In general, these case studies resulted in the following findings:

A proper estimation of the operational profile is a crucial aspect of analysing the feasibility of LNG as a fuel for short sea ships. First, the fuel consumption in ECA's relative to the total fuel consumption (together with the relevant fuel prices) determines the effect of the operational costs on the feasibility. Second, the required LNG capacity determines the size of the tank, and the impact on other design aspects such as longitudinal strength, Gross Tonnage and/or hold capacity. In addition, the size of equipment influences the investment costs;

The cases have shown that positioning the LNG tank is a specific design challenge. The impractical dimensions in combination with the regulations for positioning the LNG tank results in a limited number of spaces where the tank may be positioned. As a result, the total bending moment and/or GT may increase, the hold space may be reduced (General cargo ship), the car deck area may be reduced (ferry) or the number of cabins are affected (cruise vessel);

There are hardly any hurdles, from a technology point of view, that prevent the introduction of LNG as a fuel for short sea ships. If LNG is not feasible, than it is often because of economic reasons.

WP5 – Economical analyses, evaluation of the results and reporting

WP 5.1 – Analyses and evaluation of results and reporting

Current and future IMO regulations for clean shipping drive the development of alternative fuels and technology for reduction of harmful emissions in Short Sea Shipping. The establishment of Sulphur Emission Control Areas (SECA's) in the North Sea and the Baltic since 2015 require ship owners to take action.

Due to expected structural overcapacity in the oil market the oil price is low at the moment and expected to remain at lower levels in the near future. (see add. WP 2.5). The gas price, and the LNG price in particular is partly interlinked with the oil price. Developments with scale gas and LNG regasification at sea might result in lower gas prices in the near future as well. The renewed use of nuclear power for electrical energy in Japan has also resulted in a significant drop in demand and prices for LNG in Asia. Through these developments the absolute price difference between oil and gas is reduced.

This poses serious challenges for investments in LNG as a transport fuel for Short Sea Shipping from an economic point of view. Only international regulations with regard to emissions and or economic incentives, like the Norwegian NOx fund, seem to enable the use of LNG as a transport fuel. In the long run (30 years) it is expected that oil reserves will further decrease, while gas reserves will continue to be available in larger amounts. Renewable energy has great potential, but will contribute for a relatively small part in the overall worldwide energy consumption in the next decennia to come compared to conventional fuels.

Other alternative fuels like Liquid Petroleum Gas (LPG), methanol and hydrogen might compete with LNG. LPG remains a liquid at higher temperatures than LNG. However, LPG is more expensive, available in smaller volumes and is heavier than air so it will not dissolve and disappear, like LNG.

Methanol is often produced from natural gas. It does not require low temperatures like LNG. Yet, the energy density of methanol is lower than LNG and the price is higher than LNG.

Hydrogen is an energy carrier with no harmful emissions at all. Hydrogen can be utilised in fuel cells and combustion engines in ships. Present hydrogen production prices are very high and the required storage volume for hydrogen is six times higher than LNG. (see add. WP 5.1)

Heavy Fuel Oil (HFO) in combination with scrubber technology is a short term solution in order to comply with current SECA regulations. The payback period of scrubber technology is significantly shorter than that of LNG. When NECA regulations enter into force (expected around 2020) scrubber technology have to be combined with Selective Catalytic Reduction technology for the reduction of NOx. This poses an extra challenge with regard to required space on board of a short sea ships and also there are still some obstacles to be overcome in effective use of both scrubber and SCR technology at the same time.

Finally there are distillate fuels like Marine Gas Oil (MGO) which are refined to meet environmental requirements. These fuels require only minimal investments to the ships propulsion system and fuel supply systems. On the contrary, analysts expect fairly steep prices for these products. There is also uncertainty about refineries' capacity to meet the demand for these fuels if the majority of ship owners will transfer to MGO.

Within the Short Sea Shipping industry LNG is viewed as the best alternative to HFO and MGO. In a Lloyd's Register LNG Bunkering Infrastructure Survey of 2014 about 76% of the European ports expected to commence LNG bunkering operations within 5 years' time. In ECA ports respondents expect that by 2020 about 13% and in 2025 about 24% of the total bunkering volume for Short Sea Shipping will be LNG. As it is with traditional oil bunkering operations, barges are considered to be the best option for bunkering of LNG. (see add. WP 5.1)

WP 5.2 – Conclusions en reporting

Feasibility of LNG for short sea shipping

With regard to technical feasibility there are no show stoppers for the use of LNG as a transport fuel for the Short Sea Shipping industry. However, the regulations for LNG as a transport fuel are derived from the technical systems of dedicated LNG tankers and are often too strict for practical use in the Short Sea Shipping business. More practical and cost effective solutions are therefore recommended in order to make LNG also economical attractive.

LNG tanks cannot be installed close to the bottom or the sides of the hull and thus require costly cargo or deck space. New rules and regulations for positioning LNG tanks closer to the bottom and/or sides of the hull in combination with new constructive design and/or construction methods should be developed.

Regulations with regard to venting of LNG and safety distances can pose a problem for Short Sea Shipping with regard to air clearance of the vessels for vent stacks. In inland shipping new solutions are developed and successfully implemented. These new developments should also be introduced in the short sea shipping industry.

The emission figures of gas engines and dual duel engines can pose a problem with regard to methane slip. This particularly applies to the use of dual fuel engines and to a lesser extend to lean burn engines and gas engines. The figures of engine manufactures display that both gas engines and dual fuel engines have a significant better overall performance with regard to environmental impact than MGO and HFO diesel engines (see add. WP. 3.3). This is an important issue in the discussion of reducing harmful emissions in Short Sea Shipping.

The cost of bunker fuels has dropped dramatically over the last year. With increasing knowledge and experience in LNG and/or scrubber systems on board of ships, but limited experience in the installation and use of these solutions the costs for these systems have not gone down yet, but remained stable (or sometimes even increased). Continued governmental support for LNG initiatives in Short Sea Shipping to enable this technology to further mature is strongly recommended.

An economical comparison between MGO, HFO and scrubber or LNG as transport fuel at the moment is in favour of MGO due to the low oil prices. No additional investments are needed on board of an MGO fuelled vessel and the fuel prices for MGO are low due to a structural and long lasting overcapacity in the market. When MGO is not an option for a ship owner the next best short term investment from an economical perspective is scrubber technology. The pay back time of scrubber technology is about 2 to 5 years and many ship owners have recently favoured the installation of scrubbers on board and decided to postpone a major LNG refit or investment in new LNG ships till later date.

Emission rules with regard to reduction of NOx are expected to enter into force around 2020. Selective Catalytic Reduction systems are available for reduction of NOx, but also pose a challenge with regard to space requirements on board of existing ships (see Add. WP 5.1). Also the concurrent use of scrubber technology and SCR technology poses several challenges for the near future. In the long run LNG as a sustainable transport fuel still has some strong advantages over HFO and scrubber technology or MGO.

Conversion of existing short sea ships to LNG is a real technical and economical challenge, especially with regard to the positioning of LNG tanks and LNG systems. Current ships are designed and optimised for a specific purpose or trade. There is hardly any space left on board for the installation of large LNG tanks and/or equipment .

This also applies for the installation of scrubber systems as an alternative for LNG. However for scrubber systems there is no need for placing new fuel tanks on board. At present scrubber systems are generally installed in the superstructure of existing vessels. This is a viable solution for larger vessels where stability and longitudinal strength do not pose any problems with regard to safety. However, the first objections have already been raised by NGO's on the sustainability of the scrubber solutions, since harmful emissions are now likely to be absorbed by the seawater.

For conversion of LNG vessels, issues like longitudinal strength of the vessel and vessel stability should be taken into account as well. For smaller vessels the issues of space, strength and stability even have a greater effect on the total performance of the vessel. Vessels on short and fixed routes do have an advantage that bunkering can take place on a regular basis, reducing the size of the LNG tanks on board. Conversion to LNG of existing short sea ships only seems to be an option when the vessels are large and special LNG tank sections can be installed (in the hull or on deck) in order to create extra space on board of the vessel. For smaller short sea shipping vessels conversion to LNG seems very unlikely.

At present investments in LNG systems for newbuilding are made by ship owners and/or operators with a clear strategy on environmental friendly shipping. This is already the case in Norway where many ship owners invest in LNG powered vessels with the help of a special NOx fund. Outside of Norway there are several big players investing in LNG, e.g. Deme (Belgium) for dredging vessels built by Royal IHC, Carnival Cruises (USA) for passenger vessels built by Meyer Werft and Tallink Shuttle for fast ferries also built by Meyer Werft. They are the forerunners that will turn the tide in favour of LNG as a transport fuel.

In general the chances for implementing LNG as a transport fuel for newbuilding vessels are higher than vessels that must be converted. For newbuildings the size of the LNG installation can be taken into account during the ship design, engineering, production and assembly processes, resulting in better and relatively cheaper solutions compared to ship conversions.

However, the cost for installing the entire LNG system on board of the vessel is considerable and can only be justified when the price gap between HFO/MGO on the one hand and LNG on the other is large enough to earn back the investment in a reasonable time (5 to 7 years). With the current fuel prices this is not the case and pay back times for LNG systems on newbuilding are between 10 to 15 years, mainly depending on the bunkering interval (i.e. LNG tank size on board).

Many regard LNG as a transition fuel toward Liquid Hydrogen and the use of fuel cells. Yet, this development is believed to take at least another 30 years and should not prevent ship owners from considering the use of LNG as a transport fuel for the years to come. (see Add. WP 5.1)

Feasibility of LNG for bunkering facilities

For providers of LNG infrastructure there are many challenges to overcome. The speed and magnitude of the development of LNG shipping as a whole and in Short Sea Shipping in particular is crucial for the profitability of the LNG infrastructure in the long run.

With the current low oil prices the price difference between oil and LNG is minimal. This hardly justifies large investments from an economical viewpoint. Large LNG bunkering and storage facilities are often focussed on the gas grid and not at providing LNG as a bunker fuel for maritime transport. This can pose serious hindrances to the implementation of small scale down stream LNG bunkering facilities. Therefore also for providers of LNG infrastructure a long term strategy is required. At the moment, some major oil and gas companies are seriously investing in large scale LNG storage capability and also small scale down stream bunkering is steadily developing.

For bunkering stations there are no real technical hindrances for the implementation of LNG as a transport fuel. Standardisation of bunkering pressures is underway in road transport and is supposed to have a positive effect on the standardisation of bunkering processes for Short Sea Shipping as well.

Safety distances for LNG installations might hinder an effective and economical roll out of bunker stations in North West Europe (North Sea and Baltic Sea). The safety distances for LNG bunkering stations regarded by the Dutch government are extremely high compared to the Norwegian context where bunkering stations can be located near busy roads and houses. It is recommended that safety distances should be reviewed carefully by regulating authorities, taking also into consideration the practical experience that is built up over the last years in countries like Norway.

Prismatic tanks on board for storage of LNG as transport fuel still poses a problem with regard to the pressure difference between the LNG bunker station and prismatic tanks. Therefore Type C tanks on board offer the best technical solution for LNG as a transport fuel at the moment. The costs for these Type C tanks are considerable and form a major part of the total of LNG systems.

A careful implementation strategy for bunkering stations in North West Europe should be considered and monitored by regulating authorities in order to develop from tank trucking, to small and intermediate bunkering stations to large bunkering facilities. The investment costs for bunkering stations can be easily overlooked by the shipping industry, but form a considerable part of the LNG price in the early development stages of this sustainable transport fuel.

At present, investments in bunker vessels are quite considerable and are not regarded as cost effective at the moment. Also, the operational costs for bunkering at LNG terminals by specialised LNG bunker vessels can be extremely high at the moment.

However, bunker vessels can function as essential investments by major stakeholders in the downstream LNG chain in order to speed up the process of providing flexible bunker facilities for (potential) clients and the further development of LNG as a transport fuel for Short Sea Shipping. Several LNG bunker vessels are currently under construction and will provide a flexible LNG bunkering infrastructure in the near future.