CHALMERS

The development of a supply chain for a Liquefied Natural Gas bunkering procedure at Stena Danica

Master Thesis

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Abstract

THIS REPORT concerns a Master Thesis written in the Product Development Master program at Chalmers University of Technology in the spring of 2011. The Master Thesis is conducted in collaboration with Wärtsilä and Stena. Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets and Stena is global actor in marine-based cargo and passenger transportation.

THE PURPOSE of the Master Thesis was to develop a supply chain for liquefied natural gas to the Masthugget quay in the port of Gothenburg for supplying Stena Danica with fuel, which at the same time has to fulfil demands and requirements from stakeholders, and investigate possible placements at the ship where a liquefied natural gas storage tank could be installed. The focus was to investigate the current standing of liquefied natural gas as a marine fuel with respect to demand, infrastructure, technology and rules and regulations, and to deliver answers for some of the uncertainties among interests that are vital for increasing the acceptance of liquefied natural gas in the marine sector.

THE PROCESS started with project planning followed by research and market analysis within the area. To ensure that there actually will be an increased demand for liquefied natural gas as a marine fuel in the future, the market analysis was continuously updated during the project, which identifies driving factors of the fuel. This research resulted in a requirement specification list that supported supply chains that can be used with current technologies on the market, as well as tank placement and size. The concepts were presented for experts in the field to verify the most appropriate solution for supporting the slow-emerging process of liquefied natural gas used for propulsion in ships.

THE RESULT of the Master Thesis is a proposal of a realizable and available supply chain that can support Stena Danica with liquefied natural gas at the Masthugget quay in the port of Gothenburg, with a proposal of tank size and placement at Stena Danica that fulfil her own and the classification society's requirements.

Preface

This Master Thesis was written from the end of January 2011 until the middle of June 2011 by two Mechanical Engineering students at the Department of Product Development at Chalmers University of Technology. It was a part of the examination in which the two students had the opportunity to show competence acquired from the product development studies at Chalmers.

We would like to express our gratitude to the fallowing companies and persons for help, participants, ideas and opinions throughout the Master Thesis.

CHALMERS UNIVERSITY OF TECHNOLOGY

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Thanks!

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Nomenclature

LNG	Liquefied Natural Gas
IMO	International Maritime Organization
ECA	Emission Control Area
MGO	marine gasoil
MEPC	Marine Environment Protection Committee
MARPOL	International Convention for the Prevention of Pollution from Ships
SOx	Sulfur Oxide
NOx	Nitrogen Oxide
Ro-Ro	Roll on/Roll off
Ro-Pax	Roll on/Roll off and Passenger
EC	European Commission
DMA	Danish Maritime Authority
SECA	Sulfur Emission Control Area
SIGTTO	Society of International Gas Tanker and Terminal Operators Ltd
ISO	The International organization for standardization
DNV	Det Norske Veritas
DF	Dual-Fuel
SG	Spark-Ignited
GD	Gas-Diesel
SCR	Selective Catalytic Reduction
EGR	Exhaust Gas Recirculation
MN	Methane number
THC	Total Hydro Carbon
CO	Carbon Monoxide
CO2	Carbon Dioxide
UN	Unied Nation
LNGC	LNG Carriers
LBG	Liquefied Biogas
HFO	Heavy Fuel Oil
MSB	Myndigheten för säkerhet och beredskap

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1. Introduction

This chapter of the report will briefly discuss the background of the topic and the prerequisites for the Master Thesis and the final results of the work that has been conducted in the course (PPUX05, 30 credits) at Chalmers University of Technology in Gothenburg, Sweden.

1.1. Background

The Master Thesis project is conducted by two students from the Department of Product and Production Development at Chalmers, Wärtsilä was commissioner for the Master Thesis, and the Stena shipping company supported it with a reference ship. Wärtsilä is one of the key actors within the marine sector which offers turn-key power solution for ships and is frequently enhancing their knowledge to offer their customer solutions that are in line with the demand of the market. Today, forecasts show that there will probably be a shift in the fuel used for the marine sector due to coming international regulations, which have created uncertainties among interests regarding which fuel will be the successor. The new fuel has to fulfil some main criteria which are a well-developed and established infrastructure, secure availability of the fuel, and reliable technology that supports the properties of the fuel. *Liquefied natural gas* (LNG), which is found in large volumes in the earth and with good properties to meet the coming regulations of *Nitrogen Oxides* (NOx) and *Sulfur Oxides* (SOx) emissions, has become a promising candidate to replace the current fuel used in the marine sector; see Appendix A, emission limits. As it seems today, most of the uncertainties lie in the infrastructure and how the regulations will affect the business. Wärtsilä, which has the technology, is therefore interested in filling its knowledge gap on how the demand of LNG has been and will in future, be developing, and how the laws and regulations will look. The focus of this project has therefore been to map the market regarding trends, infrastructure and laws and regulations as well technologies that support LNG, to give Wärtsilä a view of the current standing for LNG as a marine fuel. The Stena shipping company, which is a large actor in passenger and cargo transportation at sea, has several choices to modify its ships for satisfying the regulations. It has also become interested in LNG but is uncertain about how the infrastructure will develop, as well as about which supply chains and bunkering procedure could be suitable for its ships at the Masthugget quay in the port of Gothenburg. Therefore, the Stena shipping company has provided the project with a reference ship, Stena Danica, to conduct a case study for investigation of which supply chain could be most appropriate for the Masthugget quay, where she is mooring for most of her time when she is not operating. This with help to show what the market currently offers.

1.2. Problem formulation

Demand for oil has been continuously increasing in a global world, and oil has effects that harm the environment. The *United Nations* (UN) organisation has therefore started to make proposals to national agencies over the world to create management control measures that promote more green techniques and make more environmentally harmful techniques expensive. Liquefied natural gas is a quite new and more environmentally friendly fuel in the marine shipping sector, but several issues have to be resolved before LNG can be commercialised. Currently, rules for how to manage the fuel are not finally set and have to be further developed through co-development between the shipping companies, agencies and other stakeholders. The potential for LNG in marine shipping makes it very competitive regarding stricter laws and standards that are going to be introduced in the near future for preventing emissions from the marine sector.

Most experts agree that we now are on the peak of oil production and we will not be able to increase production rates in the future. However, transportation needs will increase in the future, and marine transportation is no exception. At the same time, the environmental demands are increasing and national and international agencies put pressure on the companies to be more environmentally friendly. All this translates into new regulations on emissions, especially when it comes to SOx and NOx. This will introduce needs for after-treatment and/or very low sulfur content in the fuel if using traditional marine fuels. However, LNG has grown up to be an environmentally friendly alternative fuel in the heavy road transportation sector and is now consequently finding its way into marine transportation. Beside the ships used for LNG transportation from the LNG liquefaction plants to the users, only a very few ships have been sold to run on LNG and only one to be converted. Since the fuel is new for many marine applications, the regulations are not completely finalized, and neither is the legislation covering this area or the standards.

The problem is that shipowners do not want to retrofit their vessels before the market conditions are stabilised. Uncertainties that are fluctuating among the shipowners regarding the market are the price for retrofitting the ships to LNG operation in relation to what they earn on it, and how the regulatory framework will be developed. The other aspects are that there is no well-developed infrastructure today and the price of LNG is difficult to predict for a future market. In relation to this, the suppliers of LNG do not want to develop the infrastructure before the shipowners have retrofitted their vessels to LNG operation and thereby secured a supply chain of LNG. This has created a slow process in which no one wants to take the step to start with the handling of LNG for ships powered by LNG. Up till now, a lot of research has been conducted about the technology that supports LNG for the bunkering procedure, and most experts agree that this area is not a big issue. Most uncertainties lie instead in how the regulatory framework will develop, in price development and in infrastructure. The project has investigated the topics of what affects the market position of LNG as a marine fuel, and proposed a suitable supply chain from the output of the investigated infrastructure.

1.3. Purpose and Goals

The purpose of this Master Thesis is to investigate the future possibilities of liquefied natural gas as a marine fuel to meet the coming regulations stated by *International Maritime Organisation* (IMO), and to give an insight into how the infrastructure has developed and the future activities within the area. The Master Thesis will investigate possible supply chains which can be used to support ships with LNG. The goal is to give the Stena shipping company a proposal of how it can be supported with LNG at the Masthugget quay through the most suitable distribution channel available today, and to highlight the main functions of the supply chain for the bunkering process at Stena Danica. Furthermore, the thesis is to give proposals of the tank size and placements at Stena Danica.

1.4. Delimitations

The delimitations of this Master Thesis are the following;

- The investigation of LNG suppliers is only performed for countries near Sweden.
- Only the Stena Danica ship is studied.
- Only considering the supply chain of LNG between the supply terminal and the ship at the Masthugget quay in the port of Gothenburg.
- Only converted diesel engines or new production of LNG engines.
- The market analysis only touches upon the broader perspective.
- No detailed work at the ship, only considering the tank volume and placement.
- Only basic calculations of tank volume are conducted.
- No risk analysis will be carried out.

1.5. Deliverables

The deliverables from the project are:

- Market analysis
  - Identification of the demand and trends for LNG as a marine fuel.
  - Identification of the existing market and infrastructure of LNG for marine shipping as well as planned activities for countries near Sweden.
  - Identification of incentives to be gained from use of environmentally friendly fuel.
  - Identification of existing authorities connected with LNG in marine shipping with regard to fuel bunkering.
  - Identification of existing and coming legislation and standards connected with LNG in marine shipping.
  - Identification of the different engine technologies that support LNG and can be used in marine applications, as well as advantages/disadvantages of each of them.
- Requirements analysis
  - Develop requirements for a supply chain solution based on what is available today on the market, and investigate laws and regulations of LNG storage tank(s) placements.
- Develop and propose a supply chain suitable for delivering liquefied natural gas to Stena Danica which is possible within the inner harbour area of Gothenburg and fulfils existing laws and regulations.
  - Investigation of which supply chain concepts can be utilized for bunkering Stena Danica – advantages / disadvantages.
  - Cost of the supply chain.
- Proposal for placement of a liquefied natural gas storage tank at Stena Danica.
  - Tank and fuel bunkering station placement.

1.6. Outline of the report

This section of the report describes in brief the outline and content of the Master Thesis, from identifying the market and how LNG stands today to coming up with a suitable supply chain for bunkering Stena Danica at the Masthugget quay. The outline of the report is in chronological order with the chapters following how the project was conducted.

Chapter 1-Introduction

Gives an understanding of the background of the project, why it is conducted, and what the purpose and goals are.

Chapter 2-Methodological Approach

Explains the methods and how they have been used during the project.

Chapter 3-Market Analysis

Gives an understanding of the market regarding demand, trends, infrastructure and laws and regulations, as well technologies that support LNG, to indicate the current standing for LNG as a marine fuel.

Chapter 4-Concept Development

Describes how the concept generation has been performed for the different supply chains that can be used for bunker Stena Danica and fulfil the customer's and authority's demands. Furthermore, this chapter describes how the concept evaluation and selection sections have been executed, and finally it includes a detailed development of the final concept with tank and fuel bunkering station at Stena Danica.

Chapter 5, 6, 7-Recommendations and further work, Conclusions and Discussion

Provides recommendations and further work, discussions and conclusions for the whole project.

1.7. Final result

The outcome of the Master Thesis resulted in a developed supply chain for an LNG fuel bunkering procedure that consists of three LNG tank trucks, delivering a total volume of around 150 m^3 LNG every second day from the supply terminal in Fredrikstad (Norway) to the Masthugget quay in the port of Gothenburg where Stena Danica docks; see Figure 1 below, which illustrates the route.

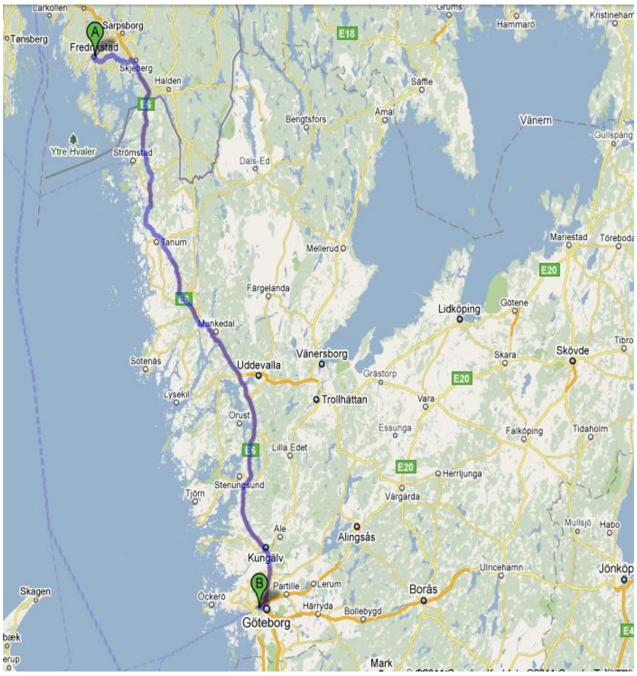


Figure 1 The route from Fredrikstad to Gothenburg.

The bunkering procedure is to take place early in the morning when Stena Danica is mooring around 5 hours. To bunker the volume of LNG that Stena Danica is consuming every second day (142.4 m^3), Stena Danica needs to have a tank capacity of 168 m^3. The results of the LNG storage tank(s) placement are proposals of different possible placements of the LNG storage tank(s) at Stena Danica and advantages and disadvantages of these. Figure 2 illustrates these areas.

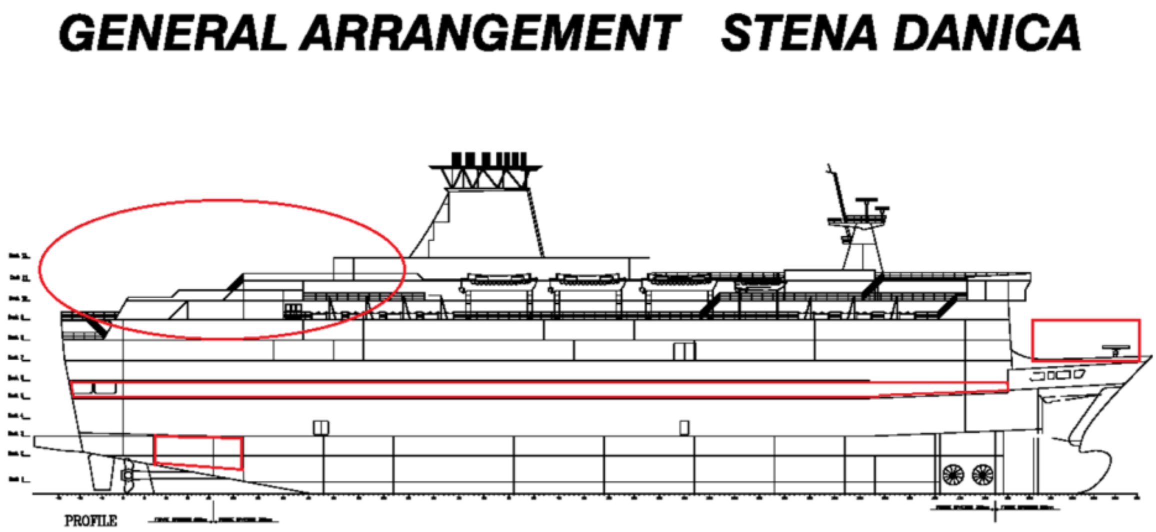


Figure 2 Possible placements of LNG storage tank(s), Stena Danica.

2. Methodological approach

The theory background includes the applied methods and how they were used, followed by tools that were used during the project.

2.1. Methodology and execution

The methodology that was used for the Master Thesis was based mostly on a Stage-Gate system that can be seen below with included parts; see Figure 3.

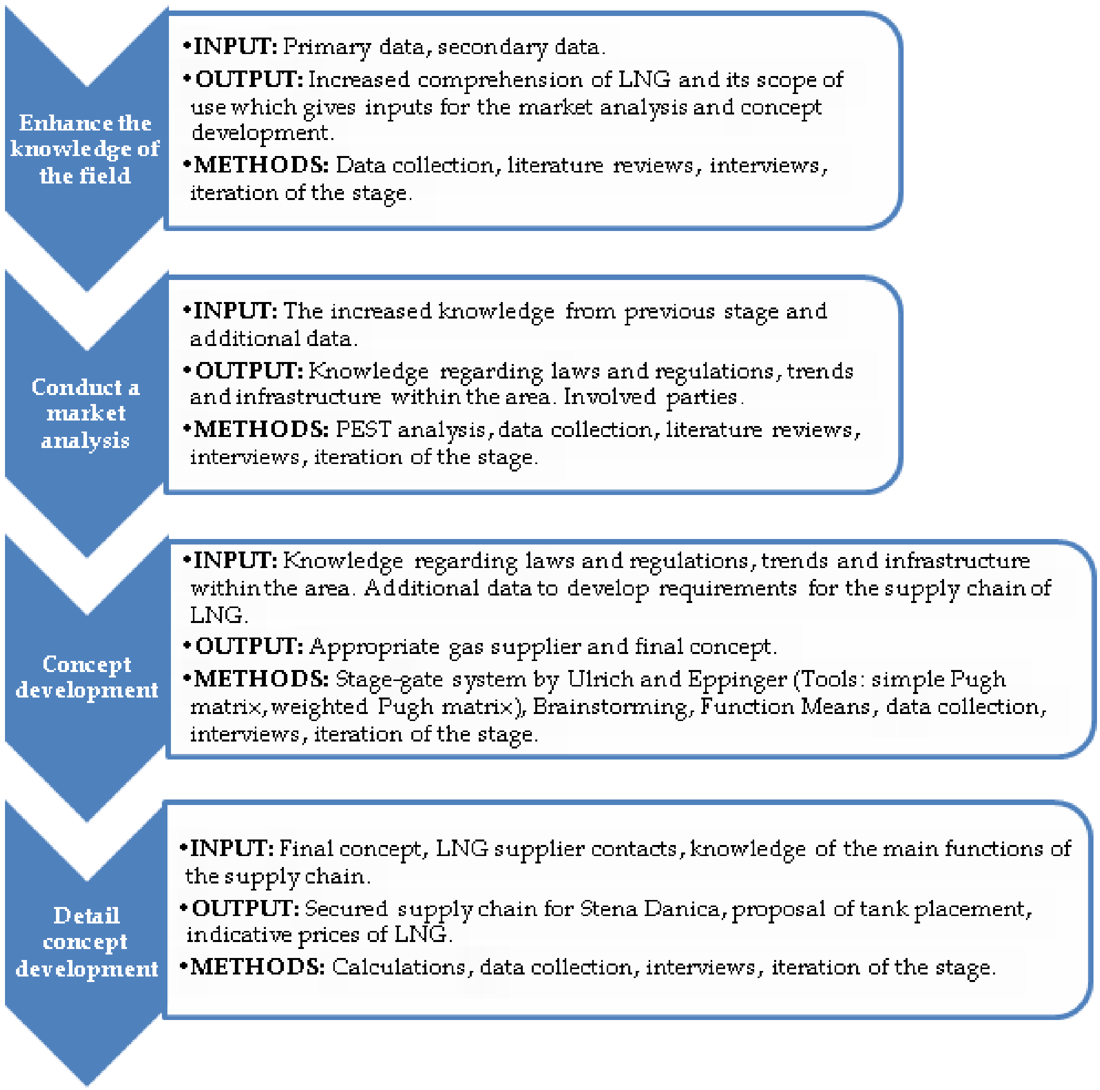


Figure 3 Project stage-gate approach.

H. Johannesson, J-G. Persson and D. Pettersson, *Produktutveckling* (2004), was considered regarding the character of the product development process and the tools and procedure from the stage-gate system provided by Ulrich K. T. and Eppinger S. D., Product Design and Development (2004) was used for the development of the supply chain; see Figure 4.

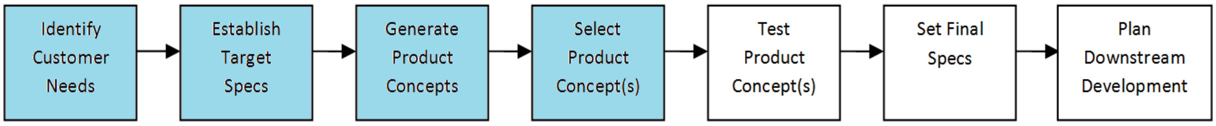


Figure 4 Stage-gate system by Ulrich K. T. and Eppinger S. D., Product Design and Development (2004).

The first step of the project was to enhance our level of knowledge since it was limited. The project started with a literature review. Information was gathered from posted reports and papers that were available, and experts in the area were contacted for interviews to give their point of view. This laid the foundation for the project and gave inputs for the market analysis and concept development sections. The most critical task in the beginning was to define the scope of the project, since the problem formulation was not finally set, and to specify what parts were appropriate to be included in each stage and how much weight each part would have in the report. Especially confusing in the beginning was what the actual problem was for the bunkering procedure. Due to the fact that our knowledge was limited initially and it was not possible to gather all the needed information directly, every stage had to go through a new review. Therefore, the development process was modified to be more flexible since iteration of the process was needed. Despite the modification, much effort was put into completing all the stages until "Select Product Concept(s)".

The second phase of the report was to conduct a market analysis which comprised an investigation of aspects that were seen as key factors for the introduction of liquefied natural gas on the market as a marine fuel and to meet the coming laws and regulations. In the market analysis, competition and trends were highlighted with a PEST analysis. Investigation was also conducted regarding the infrastructure and which laws and regulations are involved, through interviews and a literature review.

The third phase of the report comprised concept development to propose a supply chain for the bunkering procedure at Stena Danica when she is mooring at the Masthugget quay. Initially, much work was done to formulate the sub-functions for the supply chains that can support Stena Danica with LNG. "Function Means"-based configuration and concept generation was used for this task at a high abstraction level, since each sub-function at a lower level required its own requirement specification. The purpose here was mostly to use current technologies for the supply chains rather than developing new ones. A “Functional Means Tree” shows relations between the sub-functions, which also were the reason why it was preferred over a Morphological Matrix since the project needed to determine how each sub-function affects another.

At the outset, requirements were identified from the Stena shipping company, the market analysis and other research with stakeholders. Some of the requirements were in some cases too deep for the first round of evaluation and selection in the concept development process. After the sub-functions were developed, the requirements were reformulated and requirements that were at a deeper level were removed. The requirements were instead formulated to pass concepts that fulfil main functions needed for the supply chain that supports the bunkering of Stena Danica, and at the same time are available now or in the near future on the market. Finally, it was necessary to investigate what is permitted by the authorities and other interests.

Brainstorming, which is an intuitive tool for generating concepts, was used in combination with the second level of the “Functional Means Tree” to find solutions for each sub-function and create concept synthesis. After the concept synthesis was conducted and finished, a Pugh matrix was used for screening the concepts and (four in total) went further for evaluation and selection in a Kesselring matrix. In this matrix, the requirements used previously in the Pugh matrix were weighted with the help of experts’ opinions of what is most crucial and information gathered during the project. From this matrix, three concepts went further for even more investigation in terms of permission, forecasts of the future with the help of experts, and technological possibility. The initial goal was to find a supply chain that had full support from authorities and laws, but the authorities could not take many positions in the area within the time frame of the Master Thesis, and at the same time the regulatory framework was not finalized for the area. The final concept was therefore selected on the basis of what is available today and compatible with other solutions that could be of more interest in the future when the demand for LNG has increased as a marine fuel.

From the “Functional Means Tree” it was obvious that some of the sub-functions affect each other and, as mentioned earlier, it was desired to see this and if possible reduce those relations; therefore axiomatic design was in mind. The goal was to find a solution that did not have any couplings between the sub-functions and thereby did not affect each other if a change was necessary. With regard to the level of abstraction, it was not seen as an issue to resolve due to the high complexity of the system, which was seen only when the knowledge of the authors increased.

In the fourth and final phase, a further investigation of the final concept was conducted where the supply chain was developed in depth with regard to the time schedule of the ship. Calculations of the price for the distribution including the price for the fuel were done by help of the gas supplier that was seen as most appropriate for this case. It was also demanded to give a proposal of tank placement at the ship and calculations of the size for the tank(s), which were done through a ship visit, meetings and a calculation program. In this phase, the target specification was fulfilled with additional requirements given from different sources.

2.2. Applied tools

This section of the report explains the different methods and tools that have been used during this project.

Gantt chart

The Gantt chart is a project schedule that illustrates the different sub-tasks in the form of bars to facilitate the working procedure of the project. It also illustrates the start and finish dates for each sub-task. The sub-tasks comprise the work breakdown structure of the project. In some Gantt charts, the current schedule status is also shown, using a vertical line that illustrates the standing for the day (1). The Gantt chart was used to maintain high efficiency and ensure that the project went in the right direction and followed the set sub-tasks and deadlines during the Master Thesis; see Appendix B.

Market analysis

A market analysis is conducted by collecting data from different sources such as science papers, fairs, magazines, Internet databases, industry experts and authorities to fill knowledge gap of the field to be investigated. The market analysis could be done by a systematic analysis of the following main categories: customer and market segment, market potential, market share and market penetration (2). The market analysis was performed to fill the author's knowledge gap of the field and get an understanding of how Liquefied Natural Gas stands on the market today.

Interviews

Interviewing is one of the vital skills for an engineer regarding gathering information. It helps to create content for the subject that has to be investigated. The goals that most interviewers are seeking are to obtain the interviewees' opinion, knowledge and feeling about the topic. Questions with examples that are most common during an interview for gathering information from the interviewee are the following; Closed-ended questions, Semi-closed questions, Open-ended questions or leading questions, Hypothetical questions (3). Interviews for a market analysis can be either quantitative or qualitative. Primarily qualitative interviews were used to gather people's comments and opinions of the area. The questions varied from open and closed questions during the interviews.

PEST analysis

PEST analysis is a framework that describes the macro-environmental factors that are used in an environmental scanning component of strategic management. PEST stands for Political, Economic, Social and Technological (4). The PEST analysis was performed during the market analysis to give a forecast and outlook of Liquefied Natural Gas and assess its capability in terms of a successor for the current marine fuels used today.

Requirement specification

The Requirement specification is a transformation of the customer needs in order to make them measurable. The requirements specification defines the functionality that the product must fulfil, and it also ensures that no requirements are overlooked (5). The Requirement specification was used to make the customer needs measurable, that could then be used in the evaluation methods to evaluating the concepts against.

Brainstorming

Brainstorming is used to increase creativity. It is a group creativity technique designed to find as many ideas as possible for the solution of the problem. This is done by a group of people that have an innovative thinking session during a set time period. This is a good method to find solutions to a morphological matrix or solutions in a "Functional Means Tree" (2). Brainstorming was used in combination with the second level of the "Functional Means Tree" to find solutions for each sub-function and create concept synthesis.

Pugh matrix

The Pugh matrix is used to compare the concepts against an optional reference. The comparison is done with various sets of selected criteria. The different concepts compare against the reference, to rate whether they are "better than" (+), "same as" (0), or "worse than" (-) the reference for each set of criteria. After rating all the concepts against the reference with all the criteria, the results of "better than", "same as" and "worse than" are summarised to see which of the concepts fulfilled the criteria best (5). The Pugh matrix was used to reduce the number of concepts and work with the winning concepts until the next level of evaluation.

Kesselring matrix

The Kesselring matrix is a refined version of a Pugh matrix. The concepts have been refined to some extent and have been expressed in more detail. Instead of using one reference concept, different reference points could be used for the various selection criteria to avoid scale compression. In the Kesselring matrix all the criteria are weighted for their relative importance and focused on more refined comparisons with respect to each criterion. The concepts' scores are determined by the weighted sum of the ratings (5). The Kesselring matrix was used in the second evaluation round where the requirements for the concept solutions were weighted based on the demands that were most critical. During this evaluation round, different criteria and critical elements were discussed to enhance the understanding, and to make choices based on facts rather than assumptions.

Function Means

Function Means is a hierarchical structural model that includes both the product's "functional requirements" (FR) and the "solutions of each functional requirement" (DP) in a "Functional Means Tree". It also shows the relations between these. The advantages with the "Function Means" are that it is possible to describe the whole functionality of the product and their limited criteria and what solutions have been selected to fulfil these (2). "Function Means"-based configuration and concept generation was used in this project to find the main functions at a high abstraction level, since each sub-function at a lower level required its own requirement specification. The purpose was to find the main functions of the system and use current technologies for the supply chains rather than developing new ones.

Set-Based Concurrent Engineering

Set-Based Concurrent Engineering is work method that is based on performing tasks concurrently (parallelization) and is an approach used in product development projects. The basic idea of Set-Based Concurrent Engineering is that all elements that involves within a product should be taken into account early in the design phase and preceding design activities should be occurring in parallel (6). The approach was used to avoid that any elements involved in the area where missed and to develop each concept as long as possible since requirements change over time and therefore some concept might be of more interest later on in the development phase then they were initially.

3. Market analysis

The purpose of this Master Thesis, as explained earlier, is an evaluation and investigation of bunkering Liquefied Natural Gas at Stena Danica, which is a ship owned by Stena shipping company, with the help of an appropriate supply chain. It is also intended to show the future possibilities of using LNG as a fuel for ships with short times in ports. Therefore, in this section of the report a market analysis was carried out for LNG as a marine fuel. The chapter starts with a brief review of the current standing of LNG as a marine fuel with respect to its competition of the future marine shipping fuels, followed by analysis of demand, infrastructure, PEST, permission process and engine technologies.

3.1. What is LNG?

Natural gas is a gas that is extracted from the ground mostly tighter with oil, and is therefore often called associated gas, but it is also found as shale gas. By cooling the gas down to around minus 160 degrees, it transforms into a liquid state LNG. By transforming the gas into LNG, the volume is reduced by 600 times. It has a density of 420 kg/m^3 in liquefied state with energy content of 49.2 MJ/kg. Natural gas consists mostly of methane, but depending on where on the earth the gas is extracted it could consist of other substances. Table 1 below illustrates the limits of each substance of the gas mixture that LNG has to have (7).

Table 1 Illustrates the limits within which the gas mixture is considered to be LNG (7).

Material	**Minimum value**	**Maximum value**
Methane	80 %	99 %
Ethane	1 %	17 %
Propane	0.1 %	5 %
Butane	0.1 %	2 %
Pentane	<1 %	
Nitrogenous	0 %	1 %

3.2. The competition of the future marine shipping fuels

The fast-polluting fossil fuels in combination with consequent rise in fuel prices, coupled with the ever-rising demand for fossil fuel due to emerging globalization and evolution of technology, have made alternative fuels more competitive. LNG is a relatively new marine fuel and has become a more interesting option to meet future regulations regarding emissions set up by the international authorities.

Uses of LNG and phasing out of oil have large benefits for the environment, but also benefits from an economic point of view could be drawn in a long-term perspective. A world with increasing globalization requires more sustainable shipping to meet the rules and goals set by international authorities like IMO. Customers and cargo owners are also demanding environmentally friendly marine shipping. Today, CO_2, NOx, SOx and particle emissions are not stringently regulated, but harder restrictions against these emissions will be introduced as ships that do not fulfil the regulations are not allowed to enter the *Emission Control Area* (ECA).

According to www.energigas.se the international marine shipping today stands globally for approximately 4 percent of the global SOx emissions, 3 percent of CO_2 emissions and 7 percent of NOx emissions. Commitments between the countries around the Baltic Sea and North Sea have stated new requirements on the emissions in this area. Possibilities of using new engine technologies and fuels with low sulfur content are investigated. A change in this will solve most of the problems connected with sulfur and nitrogen oxide emissions in the marine shipping industry. It should also be mentioned that particulate emissions from the marine shipping sector have a negative impact on human health.

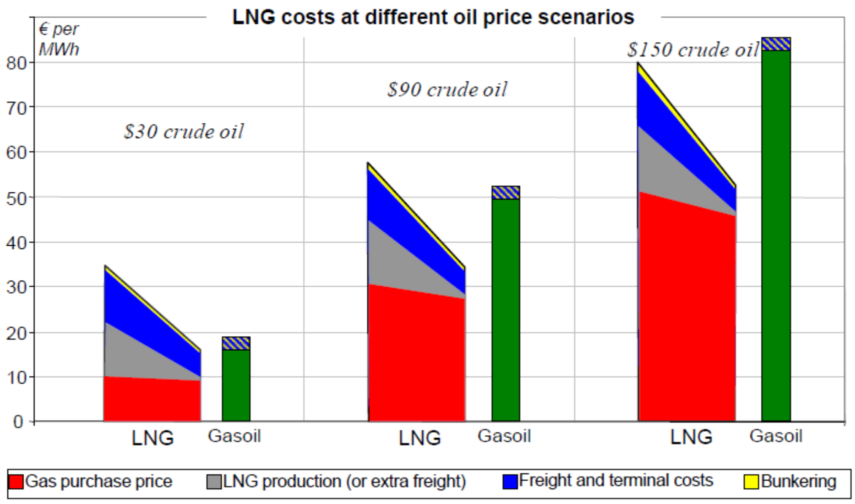
There is potential for LNG as a marine fuel, but to have a chance to compete with other petroleum-based fuels, an efficient supply chain must be implemented. From the MAGALOG report *"Maritime Gas Fuel Logistics"*, LNG is compared with *Marine Gasoil* (MGO) at varying crude oil prices according to Table 2, which shows that LNG is more competitive with a high crude oil price. This scenario would probably occur if the price of LNG is tied to the crude oil price, as the shipping company Viking Line has chosen to do.

Today, natural gas is mainly used to produce electricity and heat for cities and industries, where coal also is used. Coal is one of the major energy carriers used to produce marginal electricity, which is also the energy source that primarily controls the price of electricity in Europe. Therefore, according to *Thomas Stenhede* at Wärtsilä, natural gas and oil pricing will be decoupled and the spot price of natural gas will probably be more connected with the pricing for coal than for oil, which is the opposite of what the Swedish energy authority predicts. However, there is a consensus that beyond the spot price, there will be costs of distribution and of any taxes added to the price for the end user.

Another view is that LNG will probably be a competitive fuel in the future due to its low sulfur content within the coming emission regulations. According to experts, crude oil is near the peak of its production rate and will increase sharply in price over a short period, which increases the demand for alternative fuels that are more environmentally friendly (8). Natural gas could also serve as a bridge to the future energy system that is based on biogas, since biogas and natural gas complement each other in numerous applications.

Opponents point out that biogas can never replace marine fuels, and argue that it is wrong to say that natural gas can serve as a bridge to a biogas society. Biogas will be most unlikely to replace the current and future marine fuels in large scale, due to the fact that the volumes required are not available, at least not with today's technology and biogas production. The real issue is that biogas can take advantage of the technology developed for natural gas, since both gases have many similar application areas and this increases the acceptance for biogas.

Table 2 Cost of LNG and gasoil per MWh with varying crude oil **(9)**.



With stringent environmental requirements follow alternative technologies, but in the report *"LNG för fartygsdrift i Sverige"* the shipping industry says that the technology is not very stable for marine applications. As David Hume claimed once upon a time, "One cannot derive an Ought from an Is", and it is the same today: technologies that are not so good now could be much better in the future and should not be rejected directly. Uncertainty about investing in LNG technology has emerged due to the fact that the regulatory framework is unstable and availability of LNG in the ports is poor for the moment. Guidelines are set by IMO for on-board exhaust gas cleaning systems and the *Marine Environment Protection Committee* (MEPC), and new technologies for sounder marine shipping are under development. Many benefits could be drawn from using LNG, even despite the fact that LNG is a fossil fuel. One should not forget that expansion of LNG creates synergy effects in the form of e.g. favour for biogas as mentioned before. It can also make port environments cleaner and strengthen the municipality's environmental profile (8). As a conclusion, LNG has the possibilities to increase and become an alternative to petroleum-based fuels in marine shipping, since it meets the coming regulations for emissions of NOx and SOx in the ECA.

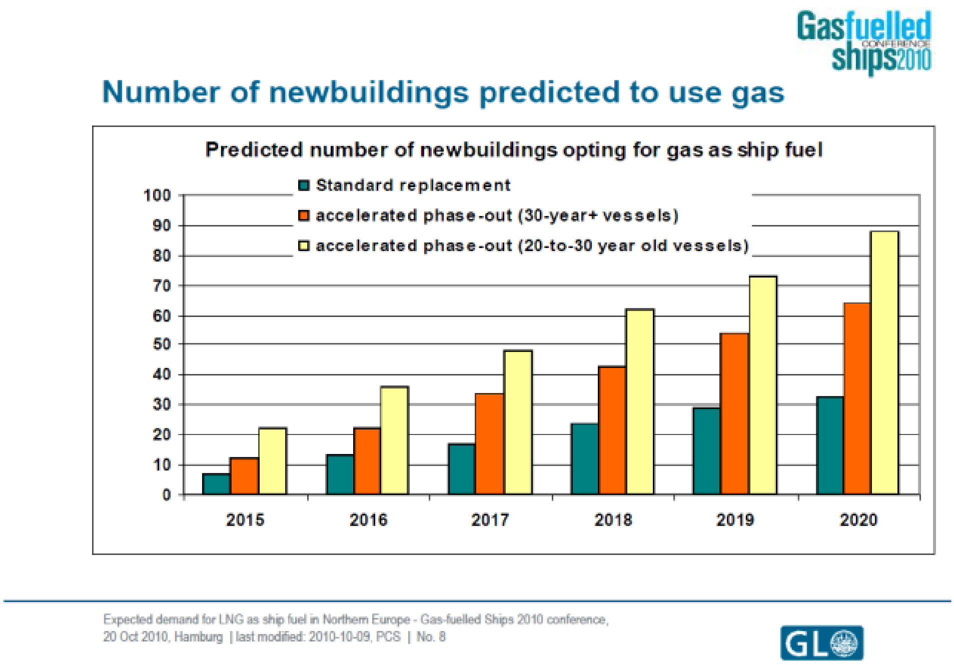
3.3. Demands on LNG in the context of fuel for marine shipping

Fuels like LNG will most probably be favoured in the future in line with stricter emission rules set by the *United Nations* (UN) agency IMO and demands for sounder marine shipping from cargo owners and customer. *The International Convention for the Prevention of Pollution from Ships* (MARPOL) is a convention that was signed on 17 February 1973 and is the most important international marine environmental convention which represents 98% of the world's shipping tonnage. The advantage with this convention is that regardless of where the flag ships are sailing, they are subjected to MARPOL's requirements. Today, most of the marine shipping is regulated through international conventions like MARPOL, and IMO is working on a legal framework. Decisions that are taken by IMO are that a reduction of SOx and NOx emissions must be achieved in the marine shipping sector. The countries around the Baltic Sea and North Sea have decided to go further and gradually restrict NOx and SOx in the area beyond the demands from IMO, and even now one can observe a reduction of those emissions. Requirements currently are set to maximum 1 percent of sulfur in the fuel and from 2015 it has to be reduced to 0.1 percent sulfur. This will probably contribute to small-scale LNG being an attractive alternative fuel for ships since the sulfur content in LNG is about zero. Similarly, progressive reduction of nitrogen oxides was started in 2000 and very stringent requirements will be introduced for engines installed in ships from 1 January 2016 that are newly constructed, or have gone through a major reconstruction and are operating in the Emission Control Area (8).

It is not easy to predict how much gas will be in demand for a certain area, but there are models of how to make an approximate estimation of the LNG demand. The first thing that has to be considered is how many vessels are operating in the investigation area, in relation to the age and type of the ship. The next step is to investigate relevant ship types for LNG and predict the fleet growth over a certain period, say between 2011 and 2020. Then one must predict how many ships will be phased out and how many will be newly built over the set time period. Finally, one must determine how many of those ships will be LNG-adapted, and after that it is easier to predict the demand for LNG after the emission targets are carried out (10).

What is seen in today's ship fleet is that it is getting older and will soon be replaced by new ships, which will make new opportunities for the shipowners to invest in engine technologies that can be driven with fuels like LNG. Table 3 illustrates the numbers of newbuildings predicted to use gas in Northern Europe, which probably will lead to more ports introducing LNG stations which will boost the growth of the infrastructure in these areas.
This is very interesting and is something that propulsion system manufacturers should raise their eyes to and consider. Just between the years 2015 and 2020 there are expected to be approximately 650 to 700 new-built vessels running on natural gas in the Baltic Sea alone. One can possibly add ships that will be retrofitted for natural gas as well, so it is obvious that there will be a huge market for engines running on LNG in the future if the forecast is correct.

Table 3 Numbers of new-built ships predicted to use gas **(10)**.



3.4. Infrastructure of LNG

This chapter will focus on identifying the LNG infrastructure and how it will expand and develop in the near future. This is to give an understanding of which LNG supply chains that could be of interest for supplying Stena Danica with LNG at the Masthugget quay in the port of Gothenburg.

LNG has been used in the energy market since 1940, but currently LNG as a fuel in the marine sector is relatively new.

The transportation of natural gas has over the years been either through pipelines where it has been possible, or by ships where the infrastructures of the pipelines have been inadequate. The problem with natural gas in its natural state is that it is costly to transport, but this has been solved by liquefying the gas. Through the possibility of liquefying the gas, a large amount of energy could cost-effectively and easily be transported by *LNG Carriers* (LNGC) to different places all around the world and the dependence on pipelines could be avoided.

Natural gas in liquefied state has a density of 420 kg/m^3 with an energy content of 49.2 MJ/kg and is 600 times smaller than the volume in its natural state. Another issue to think about especially when constructing the fuel tanks is that LNG has almost twice the volume of *Heavy Fuel Oil (*HFO), which has a density of 980 kg/m^3 and an energy content of 40.4 MJ/kg; see Appendix C. As a result, a larger tank is needed for carrying LNG taking up to four times the volume of a traditional HFO tank.

The trends for LNG have changed markedly from oil-indexed contracts to gas-indexed contracts. Today LNG is traded on a large scale on the world market with long contract periods up to 10-15 years. Such large amounts of LNG are transported by import vessels with a capacity to handle volumes up to 260,000 m^3; see Figure 5. These vessels could be up to several hundred metres long and are primarily intended to transport huge amounts of LNG from sources in the Middle Eastern countries or North Africa to countries like USA or Japan. When it comes to the LNG supply for the Swedish market, it would be on a small scale in comparison with countries like Japan. The tankers that are planned to transport LNG from the export terminals to the LNG filling stations in Sweden will contain around 7,500 m^3 to 16,000 m^3 and are called feeder vessels; see Figure 6 (8). If a smaller volume is desirable it is possible to use LNG tank trucks, which can contain up to 80 m^3 depending on what is permitted in the county but on the other hand it might be of more negative impact at the environment since the need of tank trucks increase; see Figure 6.

Figure 5 LNG tankers for large-scale marine shipping **(8)**.

Figure 6 LNG tanker for small-scale marine shipping (7500 m^3) (left) **(8)** and LNG tank truck (80 m^3) (right) **(11)**.

3.4.1. LNG terminals in Sweden

The LNG aimed for the marine sector in Sweden is planned to be imported from local areas around Sweden, such as Norway, Rotterdam and central Europe; see Figure 7. The first LNG filling station in Sweden was built by AGA in Nynäshamn, Sweden. This terminal is in operation since April 2011 and has a capacity of 20,000 m^3 LNG (12).

In the beginning, the station in Nynäshamn was aimed to provide LNG for Stockholm city's gas grid and industries around the region. Since harder regulations of emissions of greenhouse gases are coming up in the ECA regions, it also gives opportunities for ports around Stockholm to supply LNG from Nynäshamn to local ships. By doing this it is possible to support regular shipping traffic with LNG. Göteborgs Energi is also planning to build a terminal in Gothenburg which is desired to be finished in the year 2013. The aim with this station is to minimize the environmental load by supplying LNG to the regular shipping traffic.

Figure 7 LNG infrastructure for ship fuelling is being developed **(13)**.

There is also some other speculation about possible LNG ports in the future. Regarding the report "LNG för fartygsdrift", by SWECO, an analysis of different ports that fulfil the criteria to become LNG bunkering stations for the regular shipping traffic was carried out; see Figure 8. The results that came out were the following: the ports of Gothenburg, Nynäshamn, Malmö, Helsingborg, Karlshamn and Stockholm. They had the potential to have LNG stations in the future. The main criteria in the analysis for the ports were:

- to have an appropriate depth in the harbour (7-8 metres)
- sufficient berth
- surface areas

A report carried out by SSPA (14) also mentions additional criteria and geographical and technical conditions, which were:

- Identify potential locations of maritime terminals for import of LNG to Swedish ports
- Efficient links to land-based distribution and consumption
- Potential maritime markets
- Supply security
- Flexibility
- Maritime markets
- Location
- Fairways
- Turning areas
- Port layout
- Terminal design
- Risk and safety
- Interaction with others

Source: Jim Sandkvist Vice President SSPA Sweden AB

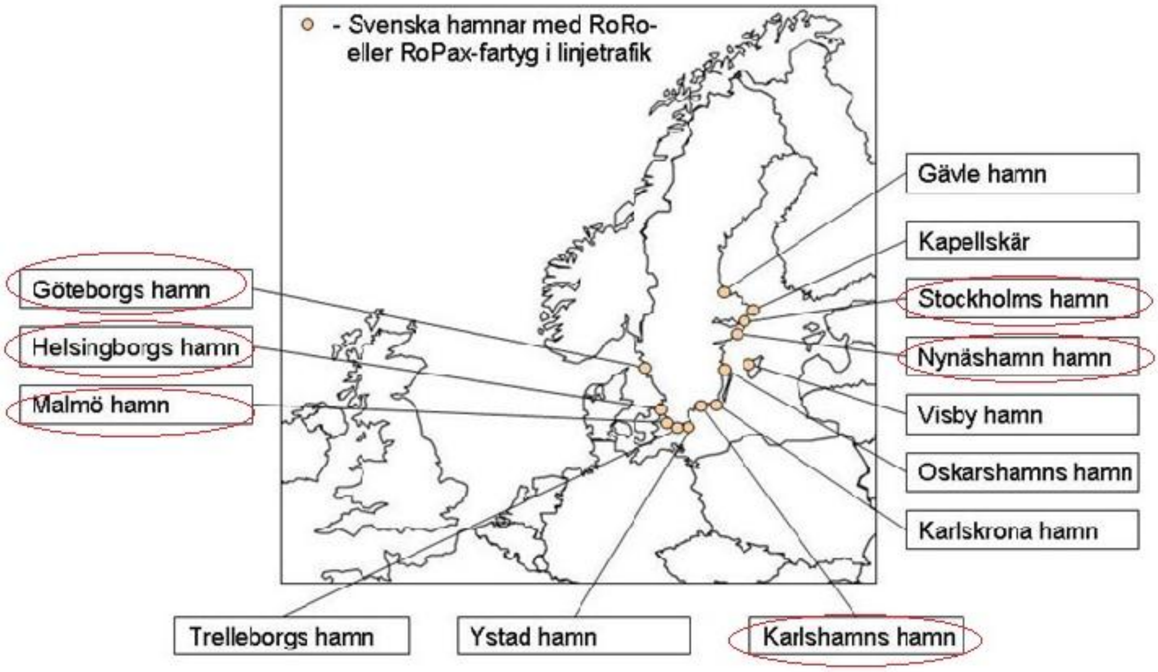


Figure 8 Potential LNG reception terminals in Sweden **(8)**.

The establishment of LNG reception terminals in the ports will only be built if there are big vessels in regular shipping traffic, such as *Roll on/Roll off* (Ro-Ro) and *Roll on/Roll off and Passenger* (Ro-Pax) vessels – and furthermore, if there are possibilities to use the terminals to supply LNG to other sectors, for example industries, gas-fired power plants and tank stations for gas vehicles etc. which will enhance the chances of new establishments (8). It should also be mentioned that natural gas is a supplement to biogas. Distribution of biogas through the natural gas grid means that natural gas can smooth out variations in biogas production and compensate for any loss in production. A major advantage of the natural gas is that it establishes a market on which biogas has the opportunity to be phased in, as the rate of production expands (15).

It is also possible to have local storage of LNG in neighbouring ports and then have bunker vessels that could transfer the LNG to the reception terminals and supply the regular shipping traffic with fuel. Potential local storage of LNG could be established and provide ports in Stockholm, Trelleborg, Ystad and Kapellskär with fuel (8).

3.4.2. The growing LNG infrastructure

The stringent 2015 emission targets set by IMO will probably boost the expansion of the infrastructure for delivering LNG to shipowners with operating vessels in short sea shipping. *Christer Farstad* of DNV Clean Technology Center in Singapore says: "We expect that LNG will emerge over the years, initially in coastal and short-sea shipping vessels, as continued pressure on shipping emissions is exerted."

Both Finland and Norway have supported the construction of LNG vessels. The government in Finland will support the new LNG-driven Viking Line ferry that is going to be constructed at STX Finland in 2011. Norway is promoting the use of LNG for propulsion at ships and the Norwegian NOx fund will support the additional building cost of two new LNG-driven ro-ro ships from SeaCargo of Norway. Today, Norway has a working LNG infrastructure and for the time being they are building a new supply terminal in Fredrikstad.

The 2015 stricter emissions requirements will also hurt the short sea shipping in Denmark; to avoid this, Denmark secured financial support from European funding to expand its LNG infrastructure for the marine shipping industry.

To satisfy the IMO mandate, shipowners will get funds from the Marco Polo scheme in the form of financial support from the *European Commission* (EC) to install and improve their LNG systems.

According to the *Danish Maritime Authority* (DMA) project manager Mogens Schröder-Bech, a complete feasibility study will be conducted of setting up a commercial LNG supply by early 2012. The study, which will be carried out by SSPA and AF, consists of the following parts;

- Technical options to retrofit short sea vessels into LNG
- Possibilities to integrate an LNG bunkering station into the existing gas grid to more easily control the gas price in comparison to other marine fuels

The EUR 1.3 million projects include also other ports, LNG terminals and gas firms around Europe, such as Fluxys of Belgium, Gasum of Finland, Energinet in Danmark, Gasnor of Norway, Energigas in Sweden and a few important ports in North Europe (16).
There is also an ongoing study of potential locations of maritime terminals that in the future could provide Swedish ports with LNG; this is carried out by the consultancy firm (SSPA) (14).

In the Baltic Sea, there are over 2000 vessels operating at any time. In the Baltic Sea alone, the shipyards' annual emissions are 135,000 tons of SOx, 400,000 tons of NOx and 1.9 million tonnes of CO_2 from the current marine fuel. The figure below illustrates the routes that the vessels are operating in, and it would be strategically right to invest in new LNG stations at the major ports as illustrated; see Figure 9 (17).

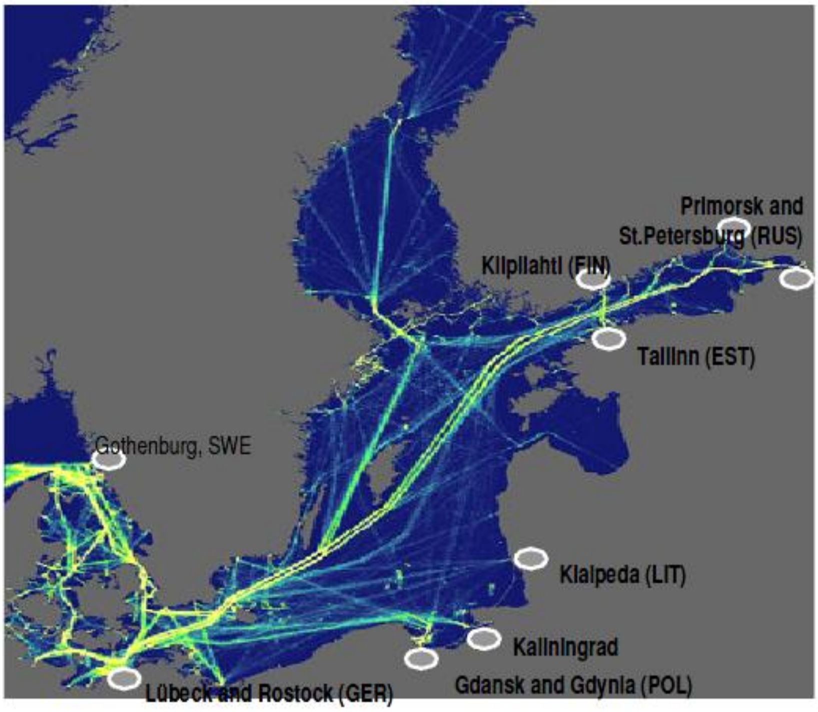


Figure 9 Operating routes in the Baltic Sea **(17)**.

Many experts trust in LNG because it is a fuel that has the potential to meet the future regulation; but to become a real alternative to bunker oil, there are some challenges to resolve. They concern both the investments in LNG terminals and, at the same time, making shipping companies, ports and energy companies favour LNG. If the aim is to cover a major geographical area, then the establishment of a usable infrastructure requires great investments (18).

Issues that also should be examined before the expansion of the LNG infrastructure are whether society is ready for dependence on individual nations with natural gas sources where unrest and war are common, and how this should be tackled.

This part shows that LNG is topical in many countries, but many issues have to be resolved before the infrastructure can develop.

3.5. The trends

The trend analysis below describes a forecast and outlook of LNG as a marine fuel and assesses its capability in terms of a successor for the current marine fuels used today. In this report four trends are described as the political, economic, social and technological perspectives.

3.5.1. Political perspective

Liquefied natural gas is not a new energy source, but with coming regulations of emissions it has become more and more interesting as a marine fuel. Today, LNG is on the list of alternative fuels that can replace current marine fuels which do not fulfil coming regulations and laws. Many activities and projects are going on around the world regarding LNG. This is due to an increased demand for crude oil followed by rapidly increasing prices of residual fuels and forecasts that a so-called peak of oil production is near (19). Another factor that has influenced the trend is rules set by the agency International Maritime Organization which are contained in MARPOL 73/78.

Many developed countries have the ability to consider the rules set by the international marine shipping authorities also have the opportunity to be involved and influence the future standards. The European Parliament has established mandatory national targets for reducing emissions. It can also be added that the marine shipping industry is a sector that has been fortunate enough to pay less attention to issues regarding pollution than land transports, which are far ahead in this area of reducing emissions. The process will be a progressive reduction to enable the industry to achieve the emission targets, and it is not yet fully determined how this should be managed. Norway is at the forefront in this area and uses a taxation system. The neighbouring state of Denmark thinks it will be affected by the 2015 emission target in the area of short sea shipping and is eager to take advantage of the experience in Norway but, instead of using taxation, to develop a commercial system.

According to MARPOL Annex VI, other provisions are about to arise in the near future as many governments set ambitious targets and enact new policies. Research also shows that newbuilding of ships are the best candidates for using LNG, and it assumes that ECA will trigger more newbuildings which will lead to increased demand for LNG. Figure 10 illustrates the Emission Control Area and Table 4 illustrates the coming demand for LNG in the Baltic Sea in connection with the emission targets.

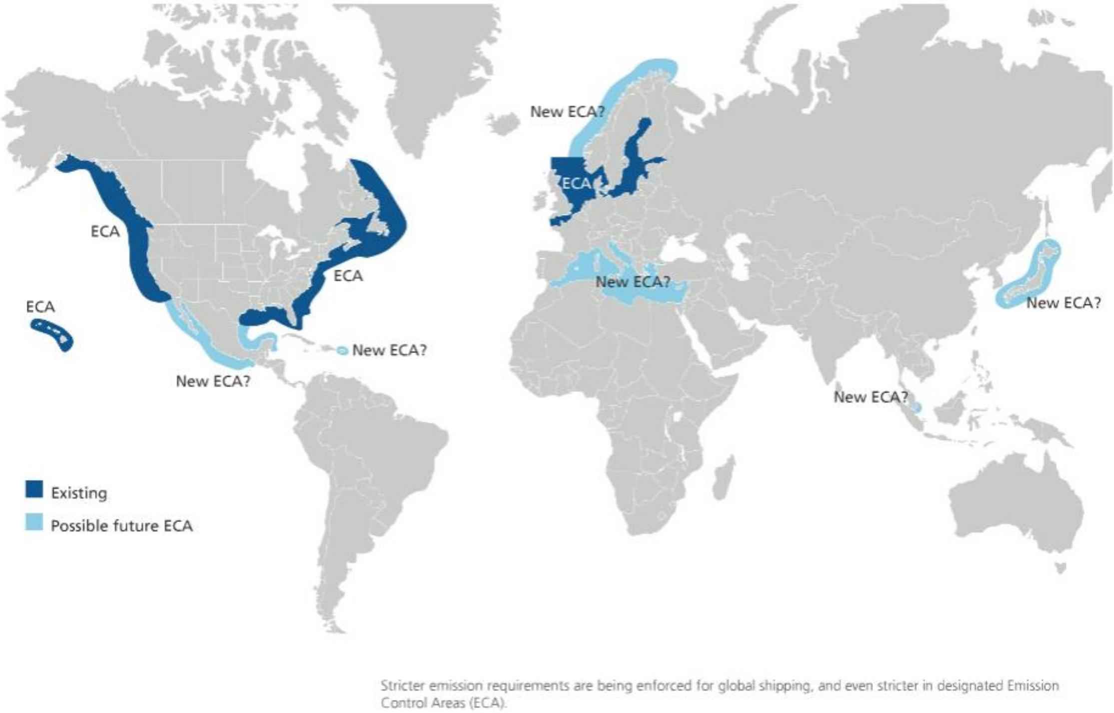
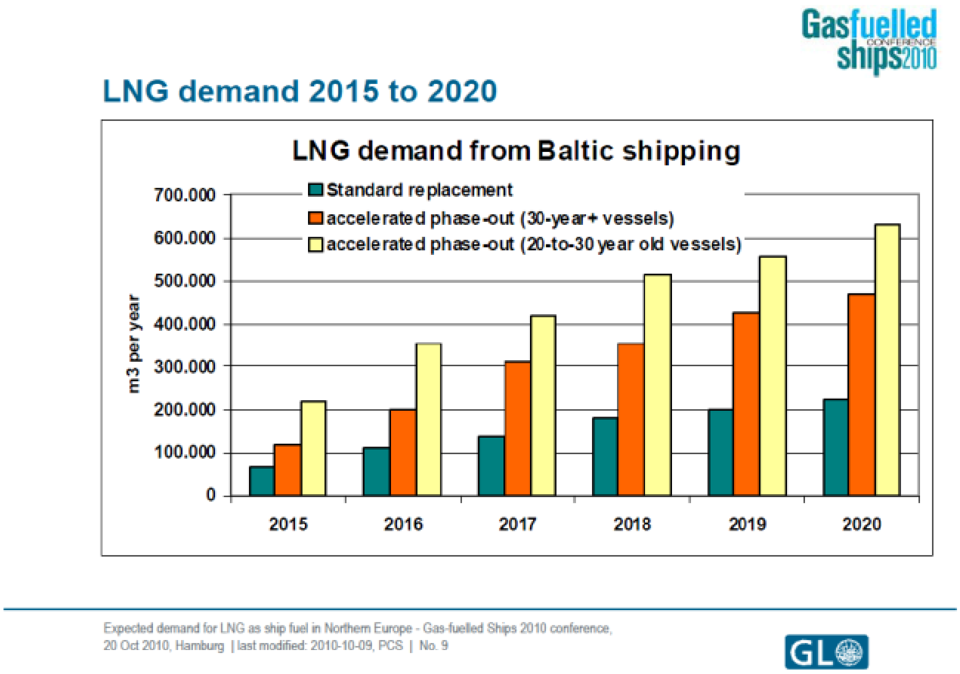


Figure 10 Emission Control Area **(20)**.

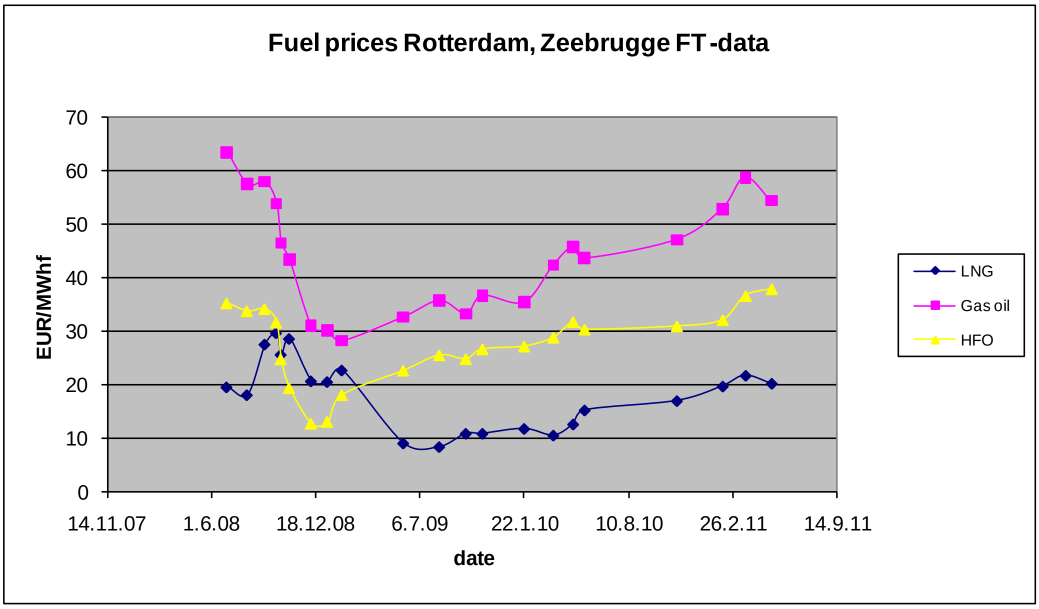
Table 4 LNG in the Baltic Sea in connection with the emission targets **(10)**.



3.5.2. Economic perspective

Due to increased focus on environmental issues by government agencies worldwide and stringent regulations, R&D in alternative marine fuels has maintained steady growth in recent years and is today one of the main topics in the marine sector. In combination with stringent regulations, the development of fuel prices illustrated in Table 5 has reached high levels and the marine shipping industry needs to find cheaper and more environmentally friendly solutions to meet coming regulations.

Table 5 Fuel price from Financial Times (16).



It is very costly for a shipping company to convert a vessel, while at the same time there is great uncertainty because the legal framework is still unstable and the infrastructure is not yet developed. As mentioned in the previous section, Norway is at the forefront in terms of incentives with its NOx fund that enables the industry to invest in environmentally friendly applications through granted support of up to 80% for the investment costs as well as operating costs in connection with emission measures applications (21). Denmark is excited by the success in the development of LNG shipping industry in Norway, as mentioned previously, and Fjordline of Denmark secured EUR 9 million in European funding to install LNG applications such as dual-fuel engines and LNG tanks.

The countries in the *Sulfur Emission Control Area* (SECA) agreed on even more stringent emission targets than were agreed at global level. At first everyone was satisfied with the decision, until people started making their own forecasts and thought that these stringent requirements could move the shipment to the land side instead and decrease the revenue in form of lost market share in the marine shipping sector. People also thought that this would result in greater pressure on the already pressed rail transportation and an increased load in land-based transport with larger emissions than what they are today. Other experts claim the opposite and say that land-based transportation will never be as cheap as the sea-based, so right now there is much discussion in the field. There are also political forces against these emission targets, since they can create competitive advantages in southern Europe, which has completely different requirements on emissions. The opposition to the emission target thinks that it will lead to loss in revenue for the companies operating in the Emission Control Area. Some even claim that it would lead to unemployment and decreased economic growth in some areas (22).

Nevertheless, we have a common goal which is to reduce the environmental impact, and if we think only of *business as usual* we can expect that the ecological footprint and distortion in biodiversity will have a much higher price. The challenge today is to make environmentally friendly alternatives more financially attractive, and that is what we have seen in Norway. Its development of LNG in the marine sector has emerged drastically in recent years, and other countries have started to investigate whether they could start to adopt policies that promote use of LNG in the marine sector. It should also be mentioned that LNG will probably be more and more competitive in connection with higher oil prices, which are increasing every year, but currently the price of LNG for the end users in Norwegian waters is 1.4 times the price of HFO (16). Initially, LNG is an expensive solution due to a weak infrastructure and expensive technology; but in a long-term perspective, LNG is a cost-competitive alternative. Many see LNG as an economical alternative compared to the price of oil, but one must not forget that the cost of distributing LNG is higher today. Over time, the price of distributing LNG will come down, and with increased oil prices it will be more competitive. The demand is not easy to estimate, but it is expected to be up to 600,000 m^3 (in 2020) from about 100,000 m^3 (in 2015) just in the Baltic Sea for LNG-powered vessels, and much more worldwide (10).

3.5.3. Social perspective

Previously, the environment was not a big issue for producers and consumers; but an increased awareness of what is happening to our environment has slowly emerged, with a strong interest in protecting our planet. In line with increased natural disasters, destruction of biodiversity and an increase in consumption, the developing world starts to become richer and catch up with the developed world, which has increased our awareness of the environment. Today, the green image has become trendy and is something that many companies aspire to and brand themselves with, and not least, many consumers think it is fashionable and it gives a sense of conscience to buy environmentally friendly products. The stringent requirement to meet more sustainable energy use and the increased demands of energy have forced society to use "greener" fuels, which will have an important role in today's and future energy society. All around the world, projects are going on that seek to solve the world's energy problems, and not least in the area of marine fuels which account for a large part of the greenhouse gases and ozone-depleting gases. Earlier, LNG was a fuel used primarily for industries and city gas grids, but it has recently received much publicity in marine shipping. As Rolls-Royce’s executive president for marine business and strategy claimed, *“LNG is a marine fuel for the future”,* an opinion he shares with many others. On the other hand, natural gas is a fossil fuel and is therefore not seen as a solution for environmental organisations despite that it is less harmful for the environment.

3.5.4. Technological perspective

To meet future environmental goals, we require not only rules but also the development of reliable techniques. Techniques for running ships at LNG in short sea operations with a fully operational system are a big challenge, but companies are working on such techniques and it seems they are on the right track. Wärtsilä, one of the major players in ship power, has developed well-functioning market solutions that offer reliable, continuous and predictable solutions to meet environmental requirements. Their potential is evident from the fact that they can deliver engines running at LNG which have lower emissions, high efficiency and fuel flexibility. There are also solutions for retrofitting old engines by converting them into LNG running engines. Unfortunately, both new LNG engines and retrofitting techniques are quite expensive so far, which makes them most suitable for new production of ships or with financial subsidies when retrofitting the old engines. But over time, these technologies will become cheaper in line with continuously improved production processes and increased demand.

As a conclusion from this strategic tool for trend analysis, it gives an understanding of the product regarding external factors that affect the products business position, market growth or decline, potential and direction at the market. As it shows, liquefied natural gas has the potential to be a successor but there are still uncertainties fluctuating among interests.

4. Concept development

This section of the report highlights the methods and procedure of evaluating the most feasible LNG supply chain for the bunkering procedure in the port of Gothenburg, based on the condition that it must be available now or in the near future. The section will also consider the placement of the LNG storage tank(s) and bunker station at Stena Danica. How the methods were used will be explained in deep and critical respects that came up during the project. Reflections on questions that arose during the project will be discussed.

4.1. System boundary

The system boundary for this Master Thesis was placed between the LNG supply terminal and the receiving ship. See the illustration of the simplified supply chain depicted below, Figure 11. It comprises the transportation of LNG from the receiving terminal to the ship which is mooring in the Masthugget quay in the port of Gothenburg, in this case Stena Danica which is owned by the Stena shipping company. The bunkering procedure, tank (type, size and placement), fuel bunkering station placement, involved authorities, rules, regulations and engine technologies that support LNG are also considered. Extraction of the gas, refinery of the gas, engineering design and installation of the LNG fuel system at the ship are excluded in this Master Thesis.

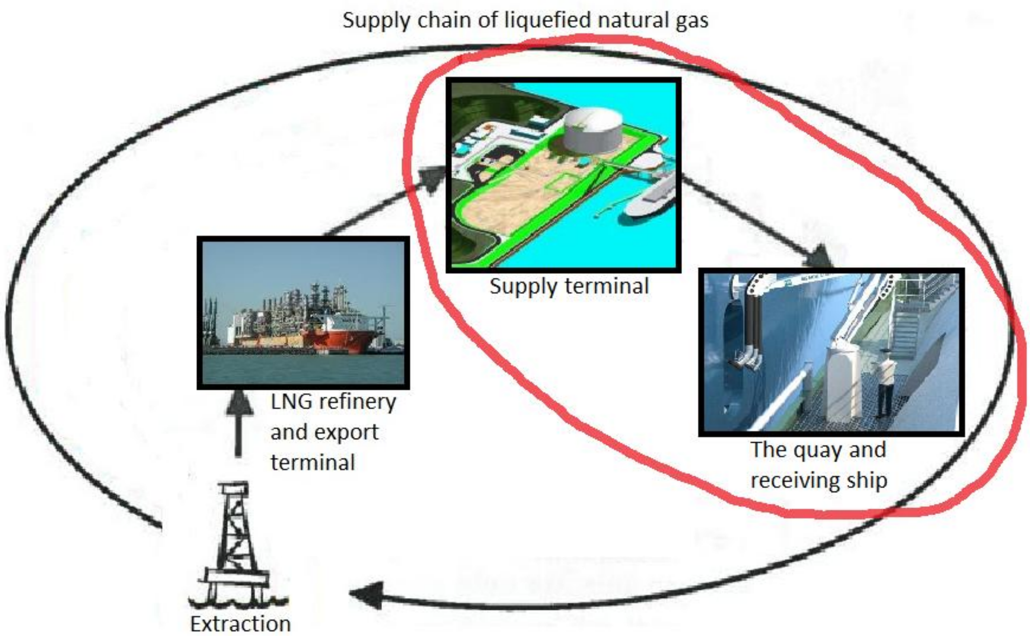


Figure 11 Simplified supply chain.

4.1.1 Motivation of the chosen system boundary

Liquefied natural gas has recently emerged on the market as a marine fuel for passenger and cargo ships, and many aspects have to be considered regarding installations, safety issues, pricing and infrastructure. For that reason, uncertainties among interests have to be resolved to promote LNG on the market, due to the fact that it is less harmful for the environment than current marine fuels. The area is wide and requires multidisciplinary knowledge and intensive work with large resources to solve the problems within the area, which the authors of the project saw quite soon. Therefore, the scope of the Master Thesis was narrowed down to the most critical parts that were identified and also desired by the stakeholders. With regard to the coming laws and regulations, shipowners are afraid to invest in LNG equipment before they know how the market will develop. Due to this fact, the project aimed to focus mostly on the supply chain of LNG, which is vital for the availability of the fuel and is a part of the uncertainties that the shipowners have. The authors decided not to go in depth with the detail design, since that was not possible within the time limit for the Master Thesis.

It is hard to predict the coming demand of the market and judge which supply chain could meet this demand when the consumption of fuel is uncertain, and at the same time verify the technology that supports the system when the laws and regulatory framework are under construction. All of this depends on various sets of parameters such as political forces, technologies and standards which have to be investigated in depth to give answers based on facts rather then assumptions.

4.2. Identifying customer needs and requirements

This section of the report deals with the needs and requirements that the LNG stakeholders place on an LNG supply chain and bunkering solution at the Masthugget quay in the port of Gothenburg. The identified stakeholders are Stena, Wärtsilä and authorities concerned.

4.2.1. What is available today

The project had as a point of departure to identify appropriate supply chains of bunkering LNG, with the help of the market analysis that was conducted earlier in the project and interviews with stakeholders. Then it was to apply them on the basis of the demands which require that the supply chain must be available today or in the near future. The problem is that shipowners do not want to retrofit their vessels before the market has stabilised. Shipowners are uncertain about some factors regarding the market, which are the price for retrofitting the ships to LNG operation in relation to what they earn on it and how the regulatory framework will be developed. The other aspects are that there is no well-developed infrastructure today and the price of LNG is difficult to predict for a future market. In relation to this, the suppliers of LNG do not want to develop the infrastructure before the shipowners have retrofitted their vessels to LNG operation and thereby secure a supply chain of LNG. These have created a slow process in which no one wants to take the step to start with the handling of LNG for ships powered by LNG. Another issue is that there is no finalized regulatory framework for bunkering of LNG to ships powered by LNG as described earlier in the market analysis. Based on this, the authors of the project have seen the supply chains that are available today or in the near future as a starting point, to move the process forward of bringing LNG into the market as a ship fuel initially and get the wheel spinning. This was also confirmed by the same opinion from one of our contacts at Wärtsilä, *Thomas Stenhede,* further strengthening our choice of how to tackle the problem and develop reasonable criteria for the elimination methods. This will be addressed in greater depth later in this chapter by using different methods and concepts described in the concept evaluation part.

4.2.2. Case study at Stena Danica and her demands

The Master Thesis also aimed to investigate which supply chain is most suitable for Stena Danica with the help of what is currently available on the market. Therefore a case study was conducted. Based on meetings and telephone interviews with Stena

Naval Architect and Chief Engineer *Lars Pennman*, the authors of this project have collected Stena's set of requirements for a new LNG bunkering process at the Masthugget quay in the port of Gothenburg. Since the study is performed at one of Stena's Ship, Stena Danica in this case, the bunkering procedure must meet her demands. Danica is a ship with short port times which continuously runs between the port of Gothenburg and the port of Frederikshavn. The bunkering process must be easy, safe and fast to perform. Stena Danica moors for 45 minutes between trips at the Masthugget quay when passengers and vehicles leave and enter the ship. This means that the bunkering process must be performed during this period in daytime. Since 45 minutes is a very short time to perform a bunkering operation, an opportunity was found to carry out the operation during the night/morning when Danica is mooring for at least 5 hours. Stena has also imposed a requirement that the bunkering procedure must be possible to perform at another place if necessary. How the LNG equipment will be placed on Danica such as the LNG storage tank, fuel bunkering station etc. is flexible, and will be designed after the supply chain has been defined and set (23). This will be investigated further in the report under the detail concept development chapter.

4.2.3. Opinions from the authorities

This part was one of the most difficult to get through. There are no similar cases previously of this kind, and the framework for the regulations is under development; see Appendix D for more detailed description. Thereby not many requirements could be provided for how the bunkering procedure should be conducted and how the bunkering station should be designed. Many contacts with the authorities concerning the bunkering process have shown that they cannot answer directly what is permitted or not, and usually require that one has to get through investigations of each element in the supply chain. This is with respect to questions concerning the supply chain scenario, fuel type, frequency and people close to the operation area. It has been time-consuming and most of the authorities that have been contacted said that they cannot take a position on this yet and until it is further investigated, but some guidelines that are available can be followed. To get permission for bunkering LNG, shipowners must carry out a risk assessment analysis for each case to prove that the system is safe, with the help of a classification society or the like which is mentioned in Appendix D.1.

4.3. Establishing target specification

The target specifications for the requirements related to the supply chain for the bunkering procedure were transportability, storage, availability etc. These were set in the initial phase; see Table 6.

Table 6 Target specification.

Target specification - Supply chain

NO:	REQUIREMENTS	D/W	VERIFICATION METHOD	TARGET V.	Unit	Primary/secondary
	R1. Transportability					
	R1.1. Must be flexible	W	estimation	yes	bin	S
	R1.2. Should not affect other operations at the quay	D	stakeholder	yes	bin	P
	R1.3. Must be available for the Masthugget quay, now or in the near future	D	stakeholder	<2	yr	P
	R2. Storage					
	R2.1. Store at least the daily consumption of LNG or more	D	stakeholder	>142	m3	P
	R3. Transfer					
	R3.1. The transfer of LNG must be within the time limit when Stena Danica is in the port	D	stakeholder	<5	h	P
	R3.2. The bunkering procedure must have sufficient area to be conducted at the Masthugget quay	D	stakeholder	yes	bin	P

For the detail concept development regarding the issues of the LNG storage tank, requirements were already developed in DNV's *"RULES FOR CLASSIFICATION OF SHIPS"* and it was therefore not necessary to develop new requirements. The same applies for the fuel bunkering station, where guidelines already have been developed for the construction of the fuel bunkering station in the *"LNG ship to ship bunkering procedure"* report.

4.4. Concept generation

This chapter will basically describe the main generic functions of the LNG bunkering procedure with respect to what the market can offer today or in the near future. It will also describe in brief the most likely supply chains of low-scale LNG.

4.4.1. The main functions

"Function Means"-based configuration and concept generation was used for this task at a high abstraction level, since each sub-function at a lower level required its own requirement specification. The purpose here was to find the main functions of the system and use current technologies for the supply chains rather than developing new ones. A "Functional Mean Tree" shows relations between sub-functions, which also was why it was preferred over a Morphological Matrix since the project wanted to see how each sub-function affects another. Axiomatic design was considered, such as Axiom 1 – independent axiom and Axiom 2 – information axiom, but could not be fully achieved when the system was too complex and certain sub-functions affected each other. Three main functions were found which are vital for the process of bunkering LNG within the harbour of Gothenburg. Those functions are storage, transport and transfer; see Figure 12. They will be further described below with typical solutions for each of them.

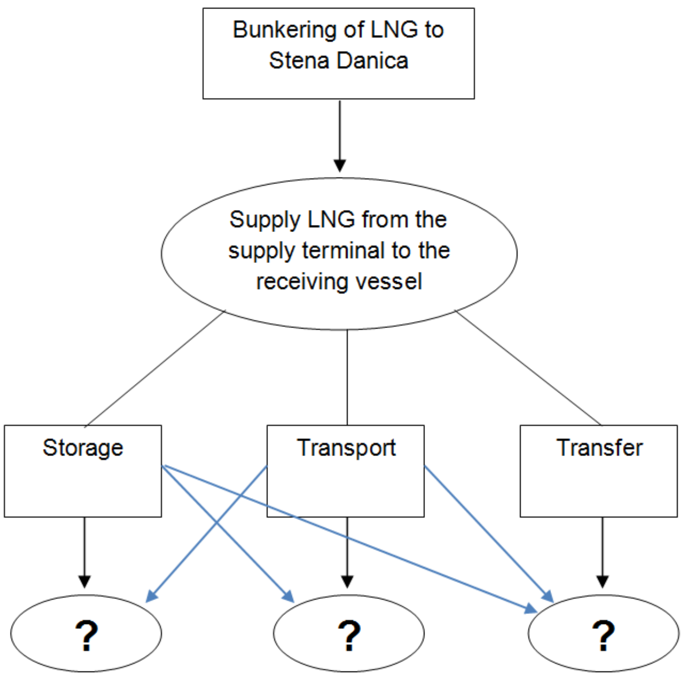


Figure 12 Functional Mean Tree.

Storage

The word storage in this sense means an LNG storage tank which is specially designed to store LNG safely and protect the liquefied gas from vaporization into the atmosphere. The tanks can be stored at LNG carriers for large-scale LNG, but installations have been conducted on smaller vessels that are powered by LNG as well. It can also be found below and above ground and at transports like trains and trucks. The most common characteristic of an LNG storage tank is that it has an ability to store LNG at very low temperature, around -162 °C, and is commonly called a cryogenic tank; see Figure 13. The sizes and geometry could vary a lot.

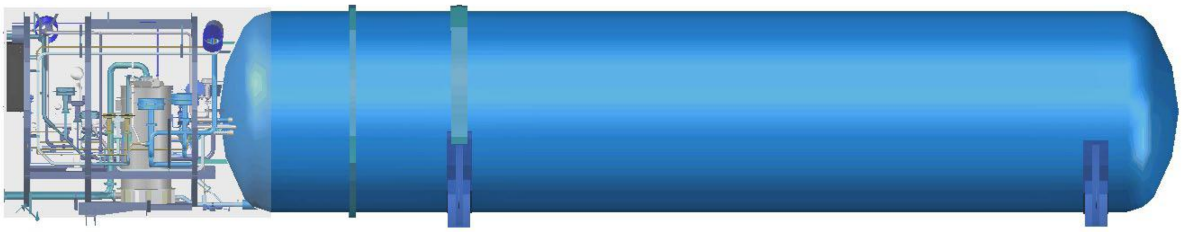


Figure 13 Layout of a LNG fuel tank **(24)**.

This project will focus on storage solutions of IMO independent pressure vessel design (Type C) tanks with cylindrical geometry which can withstand pressures up to 9-10 bar. Investigation showed that tanks with higher pressure than 10 bar in enclosed spaces would normally not be acceptable, and therefore they are not considered in this report (25). Other types can be found on the market, like Type A with maximum pressure of 0.7 bar, or Type B with maximum pressure of 0.7 bar (26). But research showed that Type C is the safest in case of increased pressure in the tank, and can store the liquefied gas longer without vaporization. The tank consists of one inner vessel with the liquefied gas and one outer vessel with insulation material and vacuum between the vessels. Perlite is most commonly used for insulation, but other insulation materials are used, like foam material layers with aluminium foil layer on one side to withstand heat radiation. Figure 14 illustrate both the inner and outer vessels of the cryogenic tank.

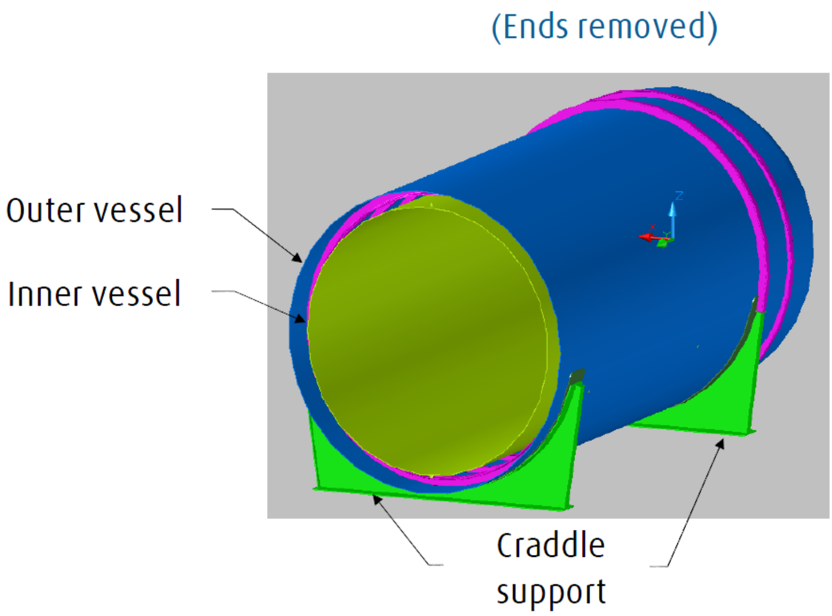


Figure 14 Visualization of the inner and outer vessels **(27)**.

This type of tank could be difficult to put into the ship due to its cylindrical shape which requires large space, and there are other types of tanks that can be formed in more complex geometries which suit the ship construction better, but those cannot withstand high pressure. The last solution is better for new production where one can design the tank in accordance with the shape of the hull. A disadvantage of LNG storage at ships up till now has been the high rate of vaporization of the gas at LNG carriers, where the gas has either been used for the engines or just released into the atmosphere to stabilize the pressure in the tank. Fortunately, recent advances in technology allow re-liquefaction of LNG that is boiled off at the ships. It has also been shown that smaller tanks offered by the market have extremely good insulation properties which can handle large pressure and can therefore store LNG for long times without any release or re-liquefaction. The hold time of LNG in the tank without boil-off could be around 14 days and above, depending on the tank type and thermal performance of the vacuum and insulation material between the vessels (28).

Besides safety issues and compatibility, another issue has to be considered with the receiving system that *Ove Norberg* at CRYO AB explained during an interview, which is the volume of the tank. An LNG tank shall not be filled more than about 95 % of its capacity in case of increased pressure, and shall not be fully empty either. Around 10 % is recommended to be left to keep the tank constantly cooled, to prevent the tank from imploding in case of fast filling. This means that only around 85 % of the tank can be utilized (28).

A typical system with (Type C) tank with fuel system that CRYO AB is offering their customers is simplified in Figure 15 below, and it can be customized for different kinds of application areas.

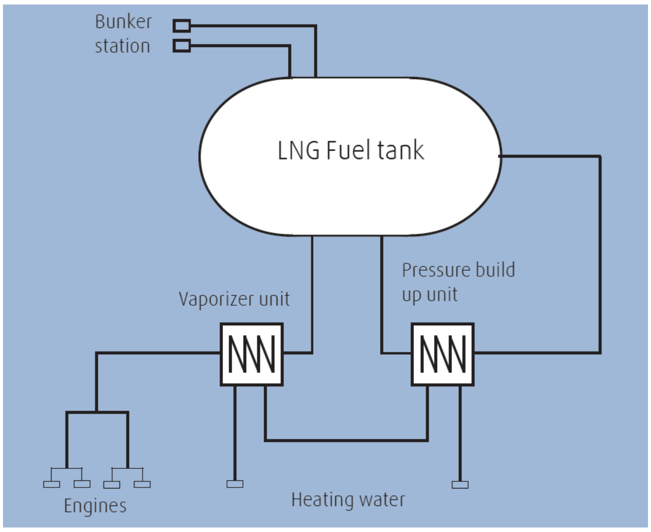


Figure 15 Outline of the LNG fuel system **(24)**.

The system includes;

- One or two LNG fuel tanks depending on the amount of fuel that is to be stored
- Vaporizer unit for vaporization of the LNG to gaseous natural gas
- Pressure build-up unit for regulation of the tank pressure
- Bunker station with filling and vapour return connection
- Piping for bunkering and delivering of natural gas to the engines

The advantage with this system compare to other manufactures is that it does not require a pump for supplying the engine with fuel. The system contains two heat exchangers: one pressure build-up heat exchanger which keeps the internal pressure stabilized (around 5 bars) to supply the engines with fuel, and one heat exchanger that vaporizes the liquefied gas before it is transferred to the engines. The heat exchangers use the water from the cooling system at the engines. This system is called a Cold-box; see Figure 16. The Cold-box also contains all controls and instrumentations that are needed for the tank operation. Another advantage is that it has pneumatic valves which are good to prevent explosion that may occur in case of a gas leakage, instead of electrically powered valves which can ignite the gas (28).

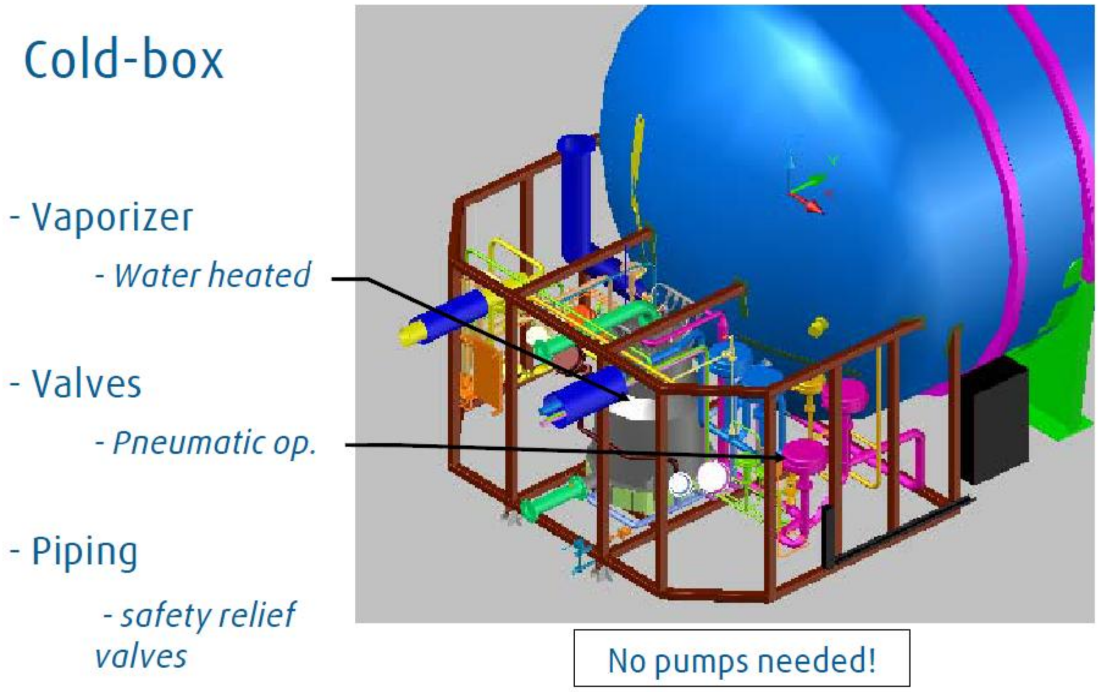


Figure 16 The cold-box **(27)**.

After research and talking to experts, a couple of pressurized cryogenic tank solutions were found that could be suitable for this project. They are all quite similar but differ in size, geometry and equipment depending on which area they are installed in, and they are depicted in Figure 17, 18 and 19.

Figure 17 An 80 m^3 Road-trailer (left) and a Cryogenic container (right) **(27)**.

Figure 18 Land-based vertical tanks (left) and horizontal storage tanks (right) **(27)**.

Figure 19 Horizontal tank for LNG-powered ships **(24)**.

Transport

Transport in this project is defined as the distribution of LNG from the supply terminal to the quay. The distribution of natural gas can be done in many ways, but the most common ways are through large pipelines or with LNG carriers which can distribute large amounts of liquefied natural gas worldwide. Transportation is one of the key parts in the supply chain of LNG, and this project focuses on low-scale LNG where other solutions are more attractive then e.g. LNG carriers. The results from the research showed the following ways of distributing low-scale LNG in the harbour area to the receiving ship:

- Road-trailer
- Train
- Bunker vessel
- Pipeline

There are advantages and disadvantages with all of them, but those will be evaluated in the concept evaluation and selection phase in the next chapter. It should also be mentioned that each solution requires its own special prerequisites. An example is that the train needs a railroad or the bunker vessel needs large manoeuvring space.

Transfer

In this project, transfer is defined as the last stage of the LNG supply chain, i.e. the bunker vessel supplies the internal LNG storage tank(s) at the receiving ship with LNG through transfer equipment. LNG needs to have a temperature of around -162 degrees; it is then more sensitive against external influences such as heat impact compared to other fuel used in the marine sector today. This means that the equipment aimed for LNG transferring must be safe, easy to handle and designed to prevent hazards. The main parts of the transfer device consist of a coupling, hose and a pump. This chapter will focus on the different parts of the transfer device. An important aspect to consider regarding the transfer of LNG is the design and the geometry of the equipment. This has to be constructed in such a way that it fulfils the desirable volume and time frame of the LNG transfer.

The couplings have to be made of a material that can withstand the extreme temperature that LNG causes so they do not become brittle. Materials that have these properties are for example stainless steel and aluminium. Another important issue is that the couplings have to be drip-free. Drip trays with vapour return manifolds must be fitted below the liquid gas bunkering connections and where leakage might occur. Each tray must have a temporarily fitted pipe or hose to lead the spill to the water without contacting the hull, to avoid serious fracture of the ship. The couplings between the LNG delivery and the receiver must also be compatible. In case of more than one coupling, the assembly must be done in the same order. It is also desirable if the couplings have a quick connect/disconnect interface for safe and fast connection/disconnection. Today, there is a company called Mann Tek which is developing couplings that will fulfil the above-mentioned statements for safe, fast and easy handling; see Figure 20 (29) (30).

Figure 20 Drip- and leak-free gas couplings from Mann Tek **(29)**.

Companies are eagerly waiting to know whether their solutions will become the basis for the future standards or not, and are offering customized solutions to meet the customers' demands fully. There is still an uncertainty since there are no regulations or standards determined for the LNG couplings. A result of this is that LNG suppliers and receivers use different types of couplings. There are mainly two types of couplings that are frequently used today, but they are old-fashioned and outdated couplings; the two types are coarse thread/trapezoidal couplings and flange/flange couplings. The negative aspects with those couplings are that they need a longer assembly time then the coupling shown in the figure above.

The hoses for handling LNG shall be designed in a material that can withstand temperatures around -196 degrees Celsius. They shall also be in good condition and designed with a sufficient length and size to avoid possible tension or chafing that could lead to fracture during the bunkering procedure. If the hoses are unlikely to short and the tension in the hoses exceeds the safety breakaway, couplings installed within the hose string should activate and minimize spillage and damage associated with drive-away and pull-away incidents; see Figure 21 (29). These breakaway couplings are under development and are not finally tested for LNG use, but the development process will probably ramp up in time with increased demand for LNG.

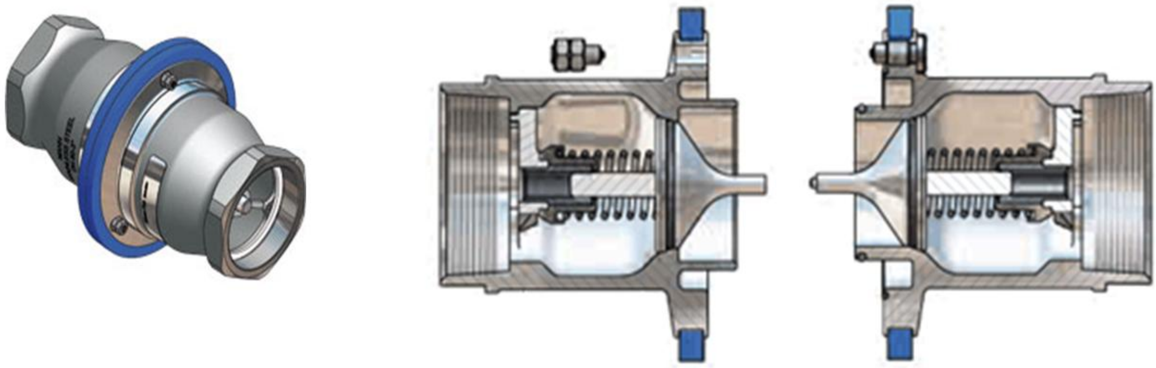


Figure 21 Marine breakaway couplings **(29)**.

In case of more than one hose, the connection must be done in the same order. To facilitate the understanding, the hoses should be marked with colour codes to minimize the risk of using an incorrect hose type. Preferably, the numbers of different hoses are to be kept to a minimum. Another important issue to consider regarding the hoses is that there should not be any sharp edges around the hose areas and the hoses should be handled with great care. Before disconnection, the hoses must be drained with N_2 to get rid of the LNG that still remains in the hoses, to avoid hazards (30). Figure 22 illustrates a bunkering procedure between a LNG semitrailer and a receiving vessel.

Figure 22 Bunkering procedure between a LNG semitrailer and a receiving vessel **(27)**.

There are mainly two different ways to transfer the LNG from the delivery source to the receiving vessel; it is possible to use either a vaporization unit or an external pump. By using high pressure inside the tanks it is possible to transfer the LNG from the cargo tank to the receiving tank without using a normal cryogenic deep-well pump, even with a higher transfer rate. The only thing the system demands is that both the cargo tank and the receiving tank can handle pressures up to approximately 10 bar. However, there is one risk of using this method: unwanted release of methane via the safety valves due to the high pressure could occur (30). If even a higher transfer rate is desired, it is possible to place an external booster pump with a higher transfer capacity at the quay, which is then connected between the LNG delivery source and the receiving vessel (31).

4.4.2. Supply chain

This part of the chapter will focus on the different possible LNG supply chains. The project group has initially decided to briefly focus on the different supply chains to the Masthugget quay, but will consider in depth the whole chain of the final concept. Figure 23 illustrates the different alternatives of the LNG supply chains within the harbour area that came up during brainstorming activity, and also opinions taken from experts during interviews. The arrows that are pointing at the star symbolise bunkering procedures that are made from the side of the ship with the help of either, train, truck or LNG station from the quay or a bunker vessel from the fairway side. The arrow that is pointing at the circle of the ship symbolises a truck with a trailer that drives into the ship and uses the container as a portable LNG storage tank that can be used as a tank for the ship. The number of trucks will vary depending on the amount of fuel that is needed as well as type of the truck, and the same concerning bunkering outside the ship. Stena Danica is mooring mainly at the Masthugget quay during the time when she is not in operation, and therefore the bunkering procedure will take place in the port of Gothenburg and not in the port of Frederikshavn.

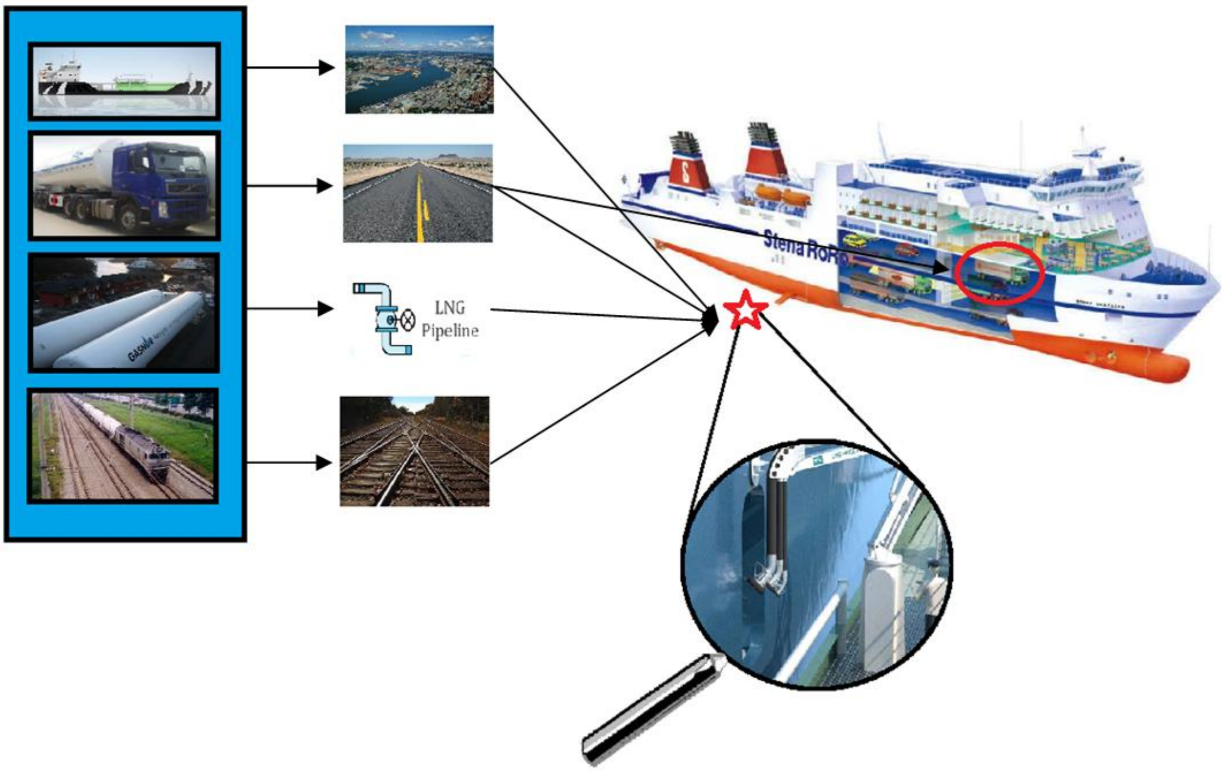


Figure 23 Supply chain of LNG within the harbour area.

The generated supply chains

Concept 1 – Train

A train fills its tanks with LNG from an LNG station. After the tanks are filled the train drives to the Masthugget quay at the port of Gothenburg. At the Masthugget quay the train stops next to Stena Danica. The bunkering process is then performed by hoses connected through couplings between Stena Danica's fuel bunkering station and the train's pump station, and the transfer of LNG can begin. See Figure 24 for illustration.

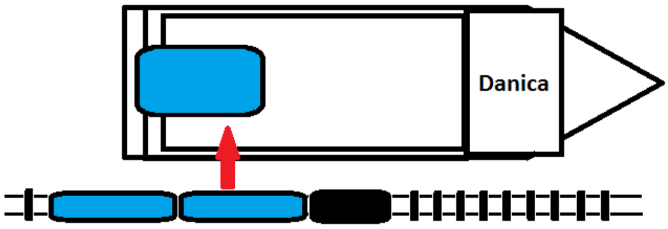


Figure 24 Concept 1 – Train.

Concept 2 – Tank truck

A tank truck starts with filling its tank(s) with LNG from an LNG station. After the tank(s) are filled, the tank truck drives to the Masthugget quay at the port of Gothenburg. At the Masthugget quay, the tank truck stops next to Stena Danica. The bunkering process is then performed by hoses connected through couplings between Stena Danica's fuel bunkering station and the tank truck's pump station, and the transfer of LNG can begin. See Figure 25 for illustration.

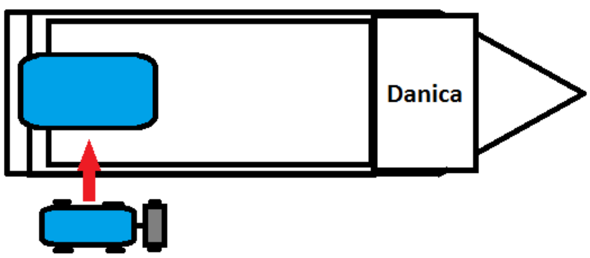


Figure 25 Concept 2 – Tank truck.

Concept 3 – LNG station

An LNG tank is placed in the vicinity of the Masthugget quay. The tank is filled up with LNG by a truck or a bunker vessel. The tank is connected with a pipeline which goes down to the quay through a liquefaction unit if necessary where Stena Danica docks. The pipeline is then connected to Stena Danica's fuel bunkering station through hoses and couplings, and the transfer of LNG can begin. See Figure 26 for illustration.

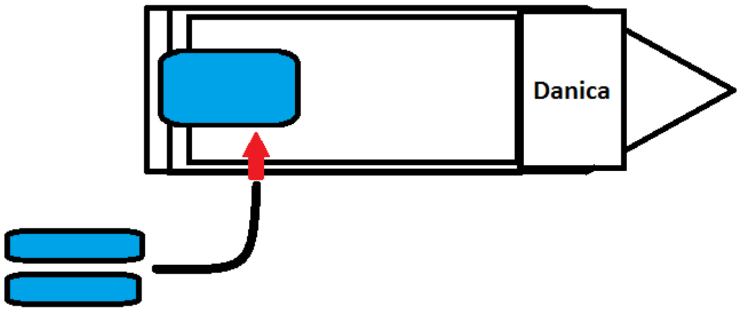


Figure 26 Concept 3 – LNG station.

Concept 4 – Bunker vessel

A bunker vessel fills its tanks with LNG from an LNG station near the sea. After the tanks are filled the bunker vessel sails to the Masthugget quay at the port of Gothenburg where Stena Danica docks. The bunker vessel moors beside the hull of Stena Danica and the hoses are then connected by couplings between the bunker vessel's pump station and Stena Danica's fuel bunkering station, and the transfer of LNG can begin. See Figure 27 for illustration.

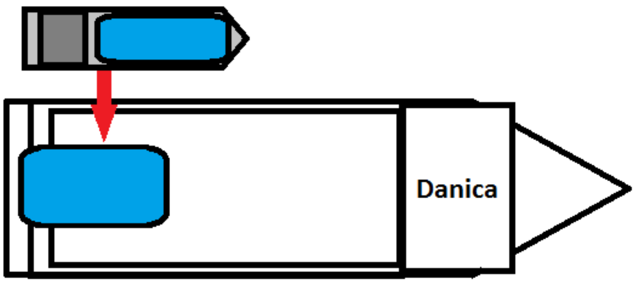


Figure 27 Concept 4 – Bunker vessel.

Concept 5 – Truck with LNG containers

A truck with container tank(s) fills the tank(s) with LNG from an LNG station. When the tank(s) are filled the truck drives to the Masthugget quay at the port of Gothenburg where Stena Danica docks. The truck drives up on Stena Danica's deck and unloads the container tank(s). The tank(s) is then attached and connected to Stena Danica's fuel bunkering station and serves as Stena Danica's LNG tank during the trip. When the tank(s) are connected, the truck drives out from Stena Danica and the bunkering procedure is finished. This procedure is repeated every time before Stena Danica departs from the Masthugget quay and is empty of fuel. The empty tank is removed by a truck before the new tank is installed. See Figure 28 for illustration.

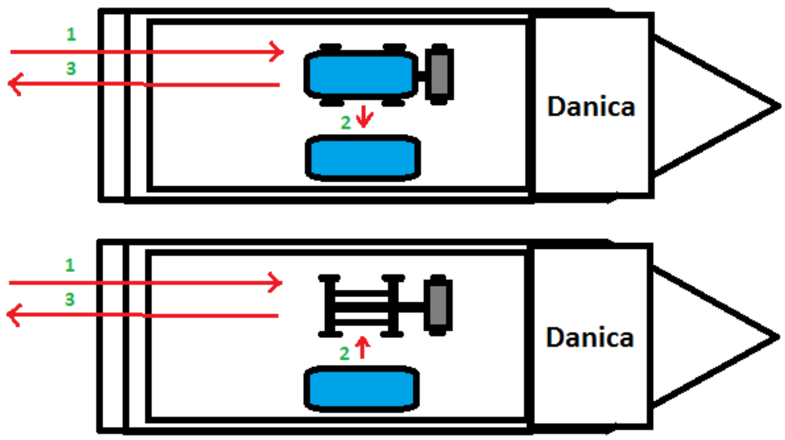


Figure 28 Concept 5 – Truck with LNG containers.

4.5. Concept evaluation and selection

The target specification that was set from the requirements became the basis for the evaluation methods for the concepts of the different supply chains that were developed. As a point of departure, the requirements for the supply chains were formulated to give maximum score in the evaluation methods for concepts that are available now on the market or in the near future and are applicable at the Masthugget quay. The first thing the project carried out was to eliminate the least appropriate solutions in a Pugh matrix in Table 7, to reduce the number of concepts and work with the winning concepts until the next level of evaluation. In the first round, only one concept was screened out, which was the train concept. This was mainly because there is no railroad available at the Masthugget quay, but the concept would certainly work at a quay that has a railroad. The four other concepts that were considered as suitable solutions for the Masthugget quay went on for further investigation. Each concept was refined after the first round and was partly determined for the outcome of the ranking phase in the second round.

Table 7 Pugh matrix.

Criteria/Concept			C1	C2	C3	C4	C5
Cr.1	**Transportability**		DATUM				
	Must be flexible.			1	0	1	0
	Should not affect other operations at the quay.			0	0	1	0
	Must be available for the Masthuggs quay, now or in the near future.			1	1	1	1
Cr.2	**Storage**						
	Store at least the daily consumption of LNG or more.			-1	1	1	-1
Cr.3	**Transfer**						
	The transfer of LNG must be within the time limit when Stena Danica is in the port.			0	0	0	0
	The bunkering procedure must have sufficient area to be conducted at the Masthuggs quay.			1	0	1	1
SUMMATION VALUE		1		3	2	5	2
		-1		1	0	0	1
		S		2	4	1	3
FINAL SUMMATION				2	2	5	1

A Kesselring matrix was used in the second evaluation round where the requirements for the concept solutions were weighted based on the demands that were most critical. The four concepts were evaluated in the Kesselring matrix which is shown in Table 8. During this evaluation round, different criteria and critical elements were discussed to enhance the understanding, and to make choices based on facts rather than assumptions. This information was collected with the help of discussion with *Thomas Stenhede* at Wärtsilä and experts, authorities and gas suppliers. Information from those interviews and meetings also gave better insight into which parts were most critical, and was therefore a great help for the second round of evaluation. One such example was the difficulty of transferring LNG during the time Stena demanded, and the investigation of which supply chains were available in the near future. It was also desired to use a pair-wise comparison of the requirements to obtain the requirements that were of the greatest importance, but this was not necessary because the information base was good enough to act upon.

Table 8 Kesselring matrix.

Selection criteria		Weight (%)	Concept 2		Concept 3		Concept 4		Concept 5	
			Rating	Score	Rating	Score	Rating	Score	Rating	Score
Cr.1	Transportability	40								
	Must be flexible.	5	5	0.25	1	0.05	5	0.25	3	0.15
	Should not affect other operations at the quay.	10	2	0.2	3	0.3	4	0.4	2	0.2
	Must be available for the Masthuggs quay, now or in the near future.	25	5	1.25	1	0.25	3	0.75	5	1.25
Cr.3	Storage	20								
	Store at least the daily consumption of LNG or more.	20	4	0.8	5	1.0	5	1.0	3	0.6
Cr.3	Transfer	40								
	The transfer of LNG must be within the time limit of Stena Danica in the port.	15	5	0.75	5	0.75	5	0.75	5	0.75
	The bunkering procedure must have sufficient area to be conducted at the Mashuggs quay.	25	5	1.25	1	0.25	5	1.25	5	1.25
		Total score	4,5		2,6		4.4		4.2	
		Rank	1		4		2		3	
		Continue?	Yes		No		Yes		Yes	

The project saw the benefits of not eliminating many concepts in the beginning before they were evaluated to a desired level; therefore, Set-Based Concurrent Engineering was considered during the elimination process. It was found that the various supply chains required different requirement specifications at a detail level in the “Functional Mean Tree” and it was therefore not interesting to break down the concepts at an early stage. As Table 8 shows, the total score difference was minimal between the concepts and therefore further and deeper investigation was required. The concept that was scored out from the Kesselring matrix was the LNG station.

LNG station: Investigation was conducted as to whether it was feasible to have an LNG station within the port of Gothenburg, but *Myndigheten för säkerhet och beredskap* (MSB) rejected that proposal immediately and said that it would never be accepted by them either. This solution would in the long run result in comprehensive management of LNG within the city of Gothenburg, and hence in no approval from their side, but they indicated that an LNG station outside of Gothenburg would be possible. Many speculations regarding an LNG station are expressed among the interested parties, but according to MSB any hint of approval for an LNG station in the port of Gothenburg is just talk. Another aspect is that it would be difficult to find space for an LNG station near the Masthugget quay, and there is evidence that such a station would bring high prices for LNG due to its small size in relation to a major terminal.

The three concepts that went on for further investigations from the Kesselring matrix were: truck with LNG container, bunker vessel and tank truck. These three concepts were then examined in order to obtain a final concept.

Truck with LNG container: This solution was considered to be technically possible, but it could not be confirmed by the authorities that it was possible to take the solution through a permit process with an approval when there are no requirements for this yet. They gave some opinions which are described below.

The gas supplier's opinion was that it would work initially but not be a solution that would work in the long run due to long assembly time of the containers. Another aspect is technology lock-in. An example of this is that, if the demand for LNG increases in the port of Gothenburg and it becomes more profitable to build a bunker vessel, the solution with container will have difficulty exploiting this bunkering technology without extensive reconstruction. It was also investigated whether it was possible to use an ordinary tank truck which drives into the ship. That was not permitted according to the Swedish Transport Agency, due to difficulties of fixing the tank truck into the hull if the ship moves a lot during a storm; and if a leakage were to occur, the wheels could be damaged due to the low temperature, which would complicate the situation even more.

Then, of course, a container is more appropriate due to the fact that it can be almost permanently attached to the hull during the trips, but in turn it would probably take more time to attach. Neither is it likely that this kind of solution would be accepted inside the ship, when the solution requires much more security arrangements compared to a totally permanent system. In view of those issues, the project group decided to not go further with this concept.

Bunker vessel: The solution with the bunker vessel has great advantages as it can take much larger volumes than the truck solution, but initially it is too expensive since the demand is still too low for the marine sector.

In addition, there is no order of a bunker vessel; AGA has provided indications that such will come in a few years, but nothing is decided yet. From an interview with Nordic LNG, regarding Pioneer Knutsen, it was discussed whether the ship could be used as a bunker vessel, but that was not permitted in Swedish fairways. They said instead that a similar bunker vessel could be built by using a hull from an old oil bunker vessel, which would decrease the price and end at around 50-60 million SEK. Uncertainties were discovered regarding how other operations in the harbour will be affected during the time when the bunker vessel is operating in the harbour. Unfortunately, nobody could take a position on this for the moment; but as a recommendation, Interim Guidelines could be used until the regulatory framework is set, with the points that the Swedish Transport Agency recommends which are described under the Permission process in Appendix D. The project group decided to not go further with this concept due to the fact that there is no bunker vessel available today and it is still uncertain when a bunker vessel will be built.

Tank truck: The tank truck solution, where the bunkering procedure is performed beside the ship at the quay, was considered to be the final winning concept, as it already has an infrastructure and it can deliver at least the daily consumption that Stena Danica needs. This solution is also flexible since one can perform it at many different quays, and it is also possible to increase the pumping capacity through a booster pump at the quay, where several trucks can connect to the booster at the same time as was mentioned previously in the transfer section of the report. Thereby it is possible to bunker a larger volume of LNG in a shorter time. Contacts with gas suppliers have shown that the price of LNG would not be as expensive as we initially expected with this solution (see indicative prices and calculations in the next chapter).

Once this supply chain is established and the demand increases, other more long-term solutions could be used, like a bunker vessel which has a similar fuel bunkering station. Bunkering LNG and *Liquefied Biogas* (LBG) are frequently used in Sweden between fuel stations and tank trucks, and questions concerning whether those rules could be adapted to the marine sector were asked. Since the scenario looks different for the fuel bunkering at ships, the rules have to be developed further. Discussion with authorities regarding which regulations have to be followed for this solution has shown that the truck must follow paragraph 2 in the ADR regulations according to MSB (32). The Maritime Department at the Swedish Transport Agency confirmed that there are no finalized rules for bunker LNG within a harbour with the help of a tank truck, but they will have a meeting about this issue with stakeholders and hopefully get an answer to whether the tank truck solution could be suitable. The same question was given to the County Board but it could not give an answer either. Finally, Nordic LNG gave information through a telephone interview that they do not think there will be any problem but the truck must choose a delivery route without passing any tunnels. The Swedish Transport Agency said that the bunkering procedure is not regulated regarding which time during the day it can be conducted, which is good since it has to be flexible. The manager for Stena Danica told us that they already bunker Stena Danica with a tank truck for the fuel to the auxiliary engines, which confirms that the LNG tank truck concept is possible to utilize in the Masthugget quay.

4.6. Detail concept development

This chapter will give a deeper investigation and development of the tank truck solution which was found to be the winning concept in the concept evaluation and selection chapter.

4.6.1 Supply chain

Derived from the part regarding concept evaluation and selection, the authors determined that the most suitable solution for transport and bunkering LNG in the port of Gothenburg with today's technology is an LNG tank truck. Nordic LNG can provide this type of truck and it has capacity to transport an LNG volume of around 50m^3; see Figure 29.

Figure 29 LNG tank truck with a capacity of 50m^3 **(33)**.

Stena Danica consumes approximately 35.6 m^3 of LNG including a safety factor of 1.3 on every trip from Gothenburg to Frederikshavn and back; see Appendix E, LNG calculations. She usually travels two trips per day and this would mean that Stena Danica consumes approximately 71.2 m^3 of LNG every day. It would then be suitable to bunker her every second day with a volume of 142 m^3. With regard to the laws in Norway which do not permit tank truck and trailer transportation of flammable goods with a capacity of 80 m^3 which CRYO AB offers, smaller tank trucks are therefore used with a capacity of 50 m^3. To fulfil Stena Danica's demand of 142 m^3 LNG every second day, three LNG tank trucks of this type are needed.

Early in the project, the fuel bunkering procedure was discovered to be most appropriate to conduct in the Masthugget quay, since Stena Danica is spending most of her mooring time there. As mentioned in chapter 3.3.2, *"The growing LNG infrastructure"*, Nordic LNG today is building a supply terminal in Fredrikstad, Norway, which will be opened for customer deliveries from July 2011. The distance between Gothenburg and Fredrikstad is just around 230 km, and will be the terminal closest to Gothenburg and the most cost-effective terminal to buy LNG from. This has been verified by comparing price proposals from other gas suppliers as well; see Appendix F, AGA. To fulfil Stena Danica's demands and time schedule, it would be most appropriate to bunker her early in the mooring between 02.00 and 09.00 when she is mooring at the Masthugget quay. This means that the LNG tank trucks from Fredrikstad should arrive around 02.00 to have plenty of time to perform the bunkering procedure.

Indicative prices for supply of LNG to Gothenburg were given from telephone interviews with *Roger Göthberg*, Sales and Business Development Manager at Nordic LNG. There are three different alternatives: buy and pick up LNG in Risavika, Norway with an own LNG tank truck, buy and pick up LNG in Fredrikstad, Norway with an own LNG tank truck, or get it delivered by Nordic LNG to Gothenburg. The different price alternatives are explained by formulas below.

Buy and pick up LNG in Risavika;

- *P = (TTF + 1.5) * 1.11 + 12.5NCV €/MWh = 41 €/MWh*

Buy and pick up LNG in Fredrikstad;

- *P = (TTF + 1.5) * 1.11 + 16NCV €/MWh = 44.5 €/MWh*

Delivered by Nordic LNG to Gothenburg;

- *P = (TTF + 1.5) * 1.11 + 17.9NCV €/MWh = 46.4 €/MWh*

Explanation of the different symbols in the formulas;

- P = Final LNG price
- TTF = gas index price, measured in gross calorific value (GCV); the index was 24.14 €/MWh on 1 April 2011
- 1.5 = Tariff cost
- 1.11 = Convert gross calorific value (GCV) to net calorific value (NCV)
- 12.5, 16 or 17.9NCV €/MWh = Operation and supply cost for Nordic LNG

Since Stena does not have any LNG tank truck today, the best solution would be to get the LNG delivered by Nordic LNG to Gothenburg initially for a price of 46.6 €/MWh. This is a very competitive price compared to what Viking Line is willing to pay for LNG, which is 40% over the price of HFO in Rotterdam (34), 41.28 €/MWh, April 13, 2011, which would give a price around 58 €/MWh for LNG; see Appendix G for detailed price calculations.

4.6.2. Transfer options

This section describes the transfer options that can be used for the bunkering of LNG in the Masthugget quay with the tank truck solution.

The pump capacity determines the amount of LNG that can be transferred to the ship, and is therefore a crucial factor that has to be considered. Interviews with Nordic LNG confirmed that it is possible to transfer the desired volume of LNG during the time Stena Danica is mooring at the Masthugget quay during the night with the pumps installed at the truck. If it is desired to increase the pumping capacity further, it is possible to install a booster on the quay, to which several tank trucks can be linked at the same time. This increases the volume per unit time, which makes it possible to bunker the ship during daytime with short port times. The pumping solutions that the project has chosen to use are cryogenic pumps due to the fact that those are already installed at tank trucks that Nordic LNG uses. Investigation of which transfer equipment shall be used showed that Nordic LNG uses equipment from the company Chart Ferox for their tank trucks, which is most appropriate for this case as well since it is approved already. An issue regarding icing at the hoses and couplings came up, but this is not a problem according to Nordic LNG because it melts fast. There are also no practical or regulatory restrictions in terms of volume and transfer rate so far. The transfer rate with a stationary pump on the quay (booster) is approximately 1 hour for 140 m^3, depending on the pump performance, while the same volume with only using the pumps at the truck could take up to 2.5 hours. Compatibility must also be achieved between tank truck and ship regarding the hoses, couplings and tanks. Requirements of how this should be designed are written in the *"LNG ship to ship bunkering procedure"* report (30).

4.6.3. Stena Danica

Tank capacity

Stena Danica travels approximately two trips every day from Gothenburg to Frederikshavn and back, and she will be bunkered every second day; hence Stena Danica needs a tank capacity that can handle a volume of around 142 m^3 LNG. A cryogenic tank can only be filled up to 95% and must have 10% of LNG left in the tank, to keep the temperature from falling as mentioned in the *"Storage"* section earlier in the report, which means that the inner vessel of the tank must have a volume of at least 168 m^3. This is different if more than one tank is used.

Tank placement and design

DNV is the classification society that Stena Danica uses and thereby its rules and regulations should be followed for the placement of the LNG storage tank(s) (35). Those rules are in turn derived from the rules and regulations in *Interim Guidelines*. The placement of the tank can be either on open deck or in an enclosed space depending on what is most appropriate for the specific case. The hull structural designs of the ship, dynamic load and general requirements for the design of the LNG storage tank that have to be considered from the classification rules (36) (26).

An excerpt of the rules from DNV and Interim Guidelines for placement of LNG storage tanks is as follows:

2.8.3 Storage on open deck

2.8.3.1 Both gases of compressed and the liquefied type may be accepted stored on open deck.

2.8.3.2 The storage tanks or in tank batteries should be located at least B/5 from the ship's side. For ships other than passenger ships a tank location closer than B/5 but not less than 760 mm from the ship's side may be accepted.

2.8.3.3 The gas storage tank or batteries and equipment should be located to assure sufficient ventilation, so as to prevent accumulation of escaped gas.

2.8.3.4 Tanks for liquid gas with a connection below the highest liquid level (see 2.8.1.2) should be fitted with drip trays below the tank which should be sufficient to contain the volume which could escape in the event of a pipe failure. The material of the drip tray should be stainless steel, and there should be sufficient separation or isolation so that the hull or deck structures are not exposed to unacceptable cooling, in case of liquid gas.

2.8.4 Storage in enclosed spaces

In addition to 2.8.3, the bullet points below must also be achieved;

- The storage tank should be placed as close as possible to the centerline
    - Minimum, the lesser of B/5 and 11.5 m from the ship side
    - Minimum, the lesser of B/15 and 2 m from the bottom plating
    - Not less than 760 mm from the shell plating
- A secondary barrier of cold resistant material (stainless steel) is required
- All connections to be installed inside a cold box made of stainless steel
- Cold box to be ventilated and insulated
- More gas detectors needed etc.

To minimize the installation cost and to facilitate the installation of the LNG storage tank(s) at Stena Danica it is preferable to have the placement on the open deck. Another important issue is the ventilation, where open deck installations promote natural ventilation compared to enclosed spaces where adequate means for ventilation have to be provided; see Figure 30.

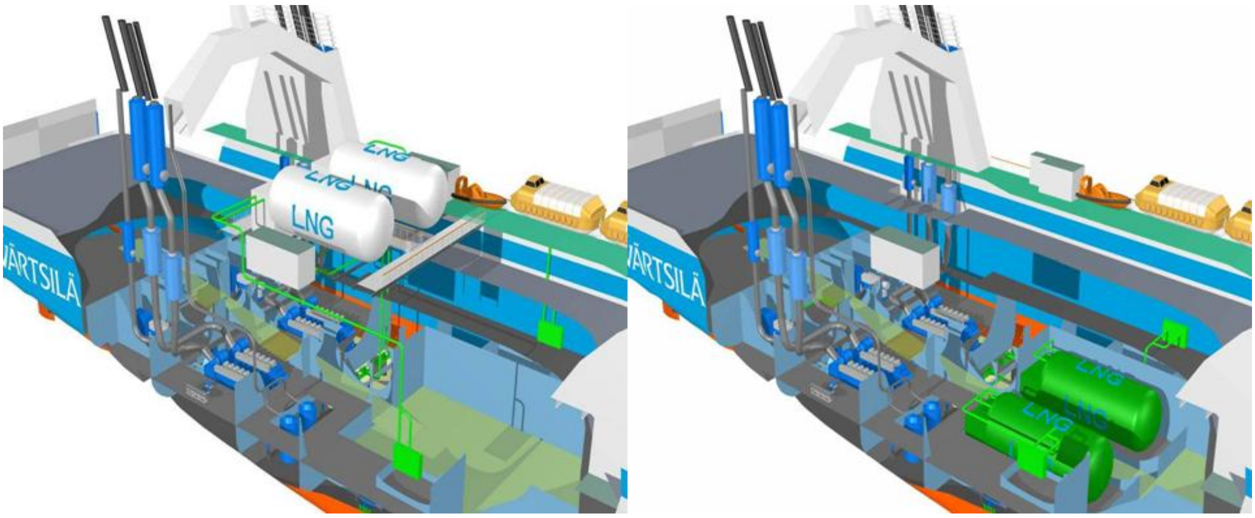


Figure 30 Left-side storage in open space, right-side storage in enclosed space **(16)**.

Proposal

During a study visit at Stena Danica, one of their employees showed suitable placements of the LNG storage tank(s) at the ship which are highlighted in the general arrangement of Stena Danica; see Figure 31. The possible placements were discussed at a meeting with DNV, which thought that it was most appropriate to have the LNG storage tank(s) on an open deck and that the stability of the ship will probably not be affected due to the small size of the tank(s). Stena Danica is a ship with many passengers and it is therefore necessary to carry out a risk assessment of different hazards that might occur with the LNG storage tank(s) according to DNV. With regard to the scope of this Master Thesis, it was desired to investigate the most appropriate area to install the LNG storage tank(s). But due to the fact that a full risk assessment of the placement has to be carried out, it will not be possible within the time limit of the Master Thesis to specify fully investigated and developed placement areas at the ship. Only proposals of placements will be delivered.

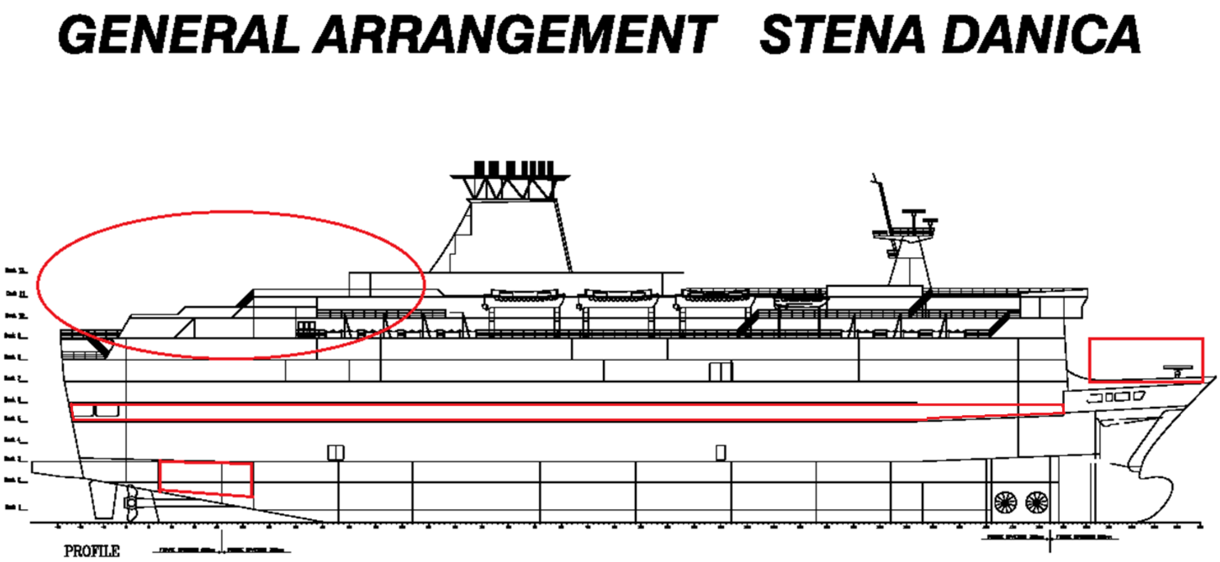


Figure 31 Possible placements of LNG storage tank(s), Stena Danica.

In the rules it is required that the tank at a passenger ship has a distance from the ship side of B/5 where B is the (breadth, moulded), in this case 28 metres. This means that the LNG storage tank has to be at least 5.6 metres from the ship side in case of installation on open deck. For enclosed space it is also required that the tank has a distance of B/15 from the bottom plating, which in this case is approximately 1.9 metres.

In Figure 31, the red square in the aft of the ship over the propeller shaft is the only void that is not used for anything special inside the ship, but is unfortunately very tight with many pipes and beams. The manager of Stena Danica proposed that it could be possible to have the tank(s) somewhere at the long sides inside the ship on Deck 5, but this will affect the load capacity since Deck 5 is a cargo deck.

In the bow of the ship, a lot of space is available but with regard to the requirements for the distance to the ship side the area available is tight. On the other hand it is preferred to have more weight in the front of the ship to facilitate planing of the ship, which makes this placement interesting. The best possibility in this case is to install the tank vertically due to the area available. A disadvantage is that this placement is close to a restaurant.

In the aft of the ship, there are plenty of spaces and opportunities to place the tank(s). It is possible to install the tank(s) between Decks 9 and 12. Today, most of these spaces are used as sun decks and restaurant, and would not need major reconstruction, but are unfortunately important places for the passengers. As mentioned before, the areas that have seemed to be appropriate for such installations have to be investigated in future through a risk analysis. Thereby only proposals can be delivered that must be investigated more fully. Reconstruction of old ships includes compromises that are inevitable, and there is always something that will be affected. In new production of ships, the designers can be freer regarding the design, but this does not mean that they can avoid the regulatory framework.

Fuel bunkering station

The requirement of the bunker station was not intended to be discussed since this was fully investigated in the report *"LNG Ship to Ship bunkering procedure"* where requirements could be found for the design of the fuel bunkering station (30); see Figure 32. Another reason for this was that the authorities could not take a position in the area within the time limit of the Master Thesis and say what is permitted or not. DNV is also providing requirements for this which can be seen in their classification rules (36). A recommendation from DNV is that the LNG storage tank(s) and its bunkering station should be as close as possible to each other, to reduce the length of cryogenic pipes that have to be installed.

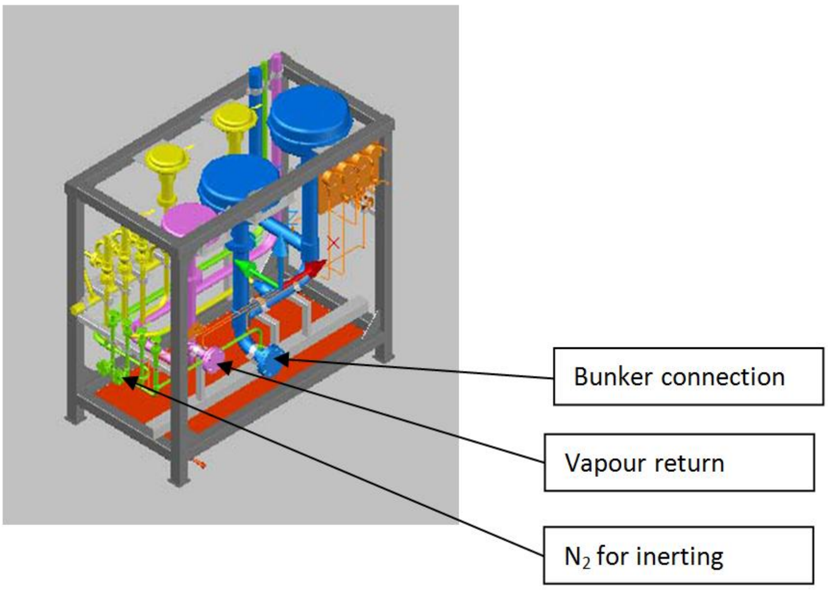


Figure 32 Fuel bunkering station **(27)**.

Redundancy

One of the uncertainties that concerned the shipowners was what to do if there is an interruption in the supply chain of LNG. The general arrangement of Stena Danica shows that she has four main engines running on HFO of the type CCM Sulzer 12 ZV 40/48; see Appendix H. Wärtsilä currently has no retrofit kit for this type of engine and it is uncertain if they will have one in the future. Instead, the project made an assumption that Stena Danica has similar engines of type Z40S which Wärtsilä has retrofit kits for; see Appendix I, engine technologies that support LNG. During operation, Stena Danica usually uses only two of those engines, which means that only two engines would be necessary to retrofit. The advantage of this is that there is redundancy installed in the engines with that solution. For example, that Stena Danica can run on HFO with the two engines that are not retrofitted, if the LNG fuel were to run out at some point or malfunction occurs of the LNG system. Another advantage is that the LNG tanks do not need a cold box for every tank since the redundancy is at the engines. Dual-fuel engine technology, which is mentioned in the Appendix I.1, is the most appropriate technology for this retrofitting and has the advantage that it can be run on HFO which gives additional redundancy to the system.

5. Recommendations and further work

This part of the report addresses recommendations to Wärtsilä and Stena that the authors came up with during the project. It also includes further work that was not within the time frame for the Master Thesis project.

5.1. Recommendations

Wärtsilä

As laws and regulations are not finally determined, it gives Wärtsilä great possibilities to affect the coming standards. They should push for their technique to obtain advantages in that their technique will be the standard in the future. By doing so, Wärtsilä will gain market share compared to other actors on the LNG market.

Stena

Stena has to collaborate with the LNG suppliers to invest in and develop an infrastructure together that will fulfil Stena's demands. Thereby they can take advantage of each other instead of slowing down the process of bringing LNG to the market in the marine sector.

5.2. Further work

There are still some aspects that need to be considered before it is possible to carry out the LNG fuel bunkering procedure at Stena Danica in the port of Gothenburg, which were not possible to take care of within the time limit of the Master Thesis. Those aspects are listed below:

- Develop requirements for the fuel bunkering station to cover all the system levels
- Perform a risk analysis for the placement of the LNG storage tank and LNG fuel bunkering procedure
- Present the defined bunkering procedure with included equipment for the Swedish Transport Agency after completing the risk analysis
- Investigate how Stena Danica will be retrofitted
- Calculate the costs for retrofit Stena Danica

6. Conclusions

This part mentions the main conclusions regarding LNG which were found during the project.

Environmental aspects of LNG:

- LNG has the possibility to increase and become an alternative to other petroleum-based fuels in marine shipping, since it meets the coming regulations for emissions of NOx and SOx in the ECA.
- Increased use of LNG can give synergy effects in the form of a clean environment in the ports, which will help to solve the problems of particles in the air in Gothenburg, increased acceptance for biogas and other industries that can use the gas etc. This means that the marine sector would not be alone in paying for the investment.
- It is important that ships powered by LNG do not leak any gas out in the atmosphere since unburned LNG is an extreme greenhouse gas.
- Natural gas is a fossil fuel and is therefore not seen as a solution for environmental organisations despite that it is less harmful for the environment.

Market aspects of LNG:

- The price of LNG and HFO is nearly the same in Sweden included distribution.
- To bring LNG to the market as a fuel for propulsion, it is necessary that shipowners and LNG suppliers collaborate and invest together.
- Large amounts of LNG are found on the Earth and this strengthens its position on the market since oil has probably reached its peak of extraction rate.
- It is most likely that the pricing for LNG will be decoupled from oil in Europe and follow the price of the energy that is used for producing marginal electricity, which is coal, since natural gas is mostly used for producing electricity and heat.

LNG for ships in Gothenburg:

- It is possible for Stena to start using LNG for its ships since Gothenburg has a secured supply chain for this.
- Authorities have difficulty dealing with questions regarding the bunkering procedure of LNG for the moment since the rules and regulations are not finalized.

LNG technologies:

- The technologies that support LNG are available today on the market.
- The technologies that support LNG are very expensive and need to be subsidised to have a chance to compete on the market.
- Reconstruction of ships to be powered with LNG is extensive and it is important to observe safety aspects in this case, since LNG differs a lot from current marine fuels.

Future of LNG:

- It is hard to predict the future demand and price for LNG.
- Companies like Wärtsilä which are large actors in the area have great opportunities to influence the standards for LNG since the standards are not developed yet.

LNG infrastructure:

- The infrastructure needs to be developed in future to enable expanding of the use of LNG for ships powered by LNG.
- It is most unlikely that an LNG terminal will be built within the port of Gothenburg, more probably outside.
- The development of the infrastructure for LNG is a slow process because the parties are unwilling to take initiatives.
- Tank trucks are most appropriate to use initially for the supply chain of LNG since they are available on the market and already have a developed infrastructure.

7. Discussion

This section discusses fundamental issues that came up during the project, and elements that affected the scope and outcome of the project.

7.1. The overall Master Thesis work

This Master Thesis has been demanding since it requires multidisciplinary knowledge, which has forced us to increase our knowledge in several areas; but it was also found interesting and we believe that this is knowledge that can be beneficial in the future. The Master Thesis has involved a lot of contacts with parties in the area and what we understood was that this subject is a real topic in the marine sector today. There are many ongoing projects in the area, but unfortunately not many are published yet. One can clearly see that there will be a shift of fuel for marine shipping within the next few years, which was seen in the market analysis that was conducted.

One of the hardest parts of the Master Thesis was to understand the problem in the beginning, since the knowledge gap was wide and, at the same time, authorities could not take a position in the area for the moment. Due to this, it was hard to find an appropriate way of attacking the problem, and since it was hard to understand how large the area is, the delimitations have been changed during the project. A fuel bunkering system is a complex system with huge amounts of requirements on different levels, and the most fundamental need in supplying the ship with fuel is to develop and secure a supply chain. The supply chain, in turn, partly affects the design of the ship with regard to which supply chain is chosen. It was therefore vital to develop the supply chain first, and take the deeper development of the requirements for the system as further work. The struggle in the development phase was to develop the overall requirements of the supply chain and be sure that they included all necessary parts of the main functions, so the elimination phase gave good outputs. Wärtsilä, which is highly affected by the coming rules and regulations within the area, is frequently increasing its knowledge to enhance its position on the market, and has therefore provided us with much information. That has facilitated the work of the Master Thesis and gave us good inputs for the market analysis. Most of the information that is available today is not outdated because it was published recently, and has therefore been of great help.

7.2. Contacts that were conducted during the Master Thesis

The stakeholders within the area that have been contacted can be divided in four categories: manufacturers, gas suppliers, consulting companies and authorities. They helped with their opinions in the area. The work with the supervisors at Chalmers and Wärtsilä has been uncomplicated and helped the progress of the Master Thesis. The fact that our supervisor at Wärtsilä works with environmental issues and with close meetings has reduced the lead times of the project. Concerning the authorities, this was completely the opposite. Some people in the area seemed to be very busy and not helpful, but mostly everyone tried to give their help. Besides Wärtsilä and Stena which where open and willing to help, gas suppliers, manufacturers and consulting companies were of great help and provided us with ideas and comments throughout the project. We also contacted people at Chalmers for advice on how to attack the problem, which gave good inputs on how the report should be structured. Considering the complex system, it is important to have close contact with people in the field, since it is under development and much can change over a short period.

7.3. Fulfilment of the objectives in the Master Thesis

The main objective was to give the Stena shipping company a proposal of how it can be supported with LNG at the Masthugget quay through the most suitable distribution channel available today, and to highlight the main functions of the supply chain for the bunkering process at Stena Danica. Another aim was to give proposals of the tank size and placement at Stena Danica.

With regard to the difficulty of the problem formulation in the beginning of the project, and a certain ambiguity about how large the area is, it was hard to decide the scope of the project. Therefore the formulation of the goal has been changed during this Master Thesis and ended up with the mentioned parts above. The most desired outcome was to cover all parts in the bunkering procedure which does not have any developed standards and rules and regulations. Thereby we could deal with Stena's and Wärtsilä uncertainties regarding this procedure, but since the authorities could not take a position in all those aspects yet, the scope of the project changed partly. The Master Thesis delivered instead a developed supply chain for an LNG bunkering procedure that can facilitate the process of change of marine fuels, which is fundamental in order to meet the coming laws and regulations and to give proposals for the tank placement. As mentioned earlier, it requires risk analysis which was not possible within the time limit and was therefore deleted from the objectives of the report. Many uncertainties have to be resolved, but what we can see is that LNG will probably be the next generation of fuel in the marine sector. We can expect that much will happen in this area within the coming years, which makes it very interesting.

7.4. Discussion of the chosen methods and approach

The authors of the project have Mechanical Engineer with focus on product development as a background which influenced both the approach of the project but also the methods used. A long the education, strategic development processes have been highlighted which was one of the reasons why this project was attacked in that way. It has also been used successfully in previous projects by the authors which were a contributing factor why it was used here as well. During the Master Thesis, several different types of analysis and development methods were used, in order to enhance decisions but also take decisions based on facts rather than assumptions. Especially in the development phases where tools were used to support the choice of concepts but also in the market analysis where analysis tools were used to enhance the knowledge of the market position of LNG and driving factors for introducing LNG as a marine fuel. This was important since the outcome gave relevance to investigate LNG further.

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Appendices

Appendix A; Emission limits

This section is a description of the Tier standards and its levels of NOx in ECA and SOx limits in SECA.

A.1. NOx and SOx emission limits

According to the IMO:s emission rules (International Convention on the Prevention of Pollution from Ships) as described in the MARPOL Convention has established protocols which has set standards with limits off NOx and SOx emissions and ozone depleting substances. The NOx standards are usually referenced as Tier I, II and III standards.

Tier I applies retroactively to marine engines above 130 kW installed on vessels built from 1st January 2000 or vessels that have undergone a major reconstruction from that date. The regulation also includes floating and fixed rigs and drilling platforms but there are exceptions for emissions that are direct associated to exploration and / or handling of seabed minerals. The rule also applies retroactive for diesel engines with a cylinder capacity of more than 90 liter and output of more than 5000 kW installed from 1st January 1990 but before December 31st, 1999.

Tier II applies at ships that are constructed, or have gone through a major reconstruction on the engines from January 1st, 2011.

Tier III applies at ships that are constructed, or have gone through a major reconstruction on the engines from January 1st, 2016 and operating in ECA. An exception applies to vessels operating outside ECA, where the emission requirements are the same as in Tier II. The requirements in Tier I, II and III standards can be seen in Table 9 (37).

Table 9 shows the standards and requirements for Tier I, II and III **(25)**.

MARPOL Annex VI NOx Emission Limits				
Tier	Date	NOx Limit, g/kWh		
		$n < 130$	$130 \leq n < 2000$	$n \geq 2000$
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96
† In NOx Emission Control Areas (Tier II standards apply outside ECAs).				

The regulations have also introduced a cap on sulfur content of fuel oil and thereby make it easier to measure, reduce and control SOx emissions. There exist special caps of the sulfur content in the fuel for ships operating and passing in SECA which are more stringent than the global levels. The limits for sulfur in the fuel and there implementation dates for each area are listed in Table 10 below (38).

Table 10 Shows the limits for sulfur in the fuel and there implementation dates for each area **(38)**.

<table>
<tr><th colspan="3">MARPOL Annex VI Fuel Sulfur Limits</th></tr>
<tr><th rowspan="2">Date</th><th colspan="2">Sulfur Limit in Fuel (% m/m)</th></tr>
<tr><th>SOx ECA</th><th>Global</th></tr>
<tr><td>2000</td><td>1.5%</td><td rowspan="2">4.5%</td></tr>
<tr><td>2010.07</td><td rowspan="2">1.0%</td></tr>
<tr><td>2012</td><td rowspan="2">3.5%</td></tr>
<tr><td>2015</td><td rowspan="2">0.1%</td></tr>
<tr><td>2020[a]</td><td>0.5%</td></tr>
<tr><td colspan="3">a - alternative date is 2025, to be decided by a review in 2018</td></tr>
</table>

Appendix B; Gantt chart

Gantt Chart

- **Project Name** : Evaluation and implementation of environmental measures within Wärtsilä
- **Project Description** : Evaluation and implementation of environmental management control measure
- **Project Length** : 20 Weeks
- **Start Date** : 24-jan-11 — End Date: 13-Jun-11 — Number of Weeks: 20
- **Working Days** : Monday - Friday
- **Today's Marker** : Yes
- **Holiday's Marker** : Yes

Level	Task	PIC	Start Date	Finish Date	WD	DC	DR
1	**Project planning**	**J&R**	**24-jan-11**	**04-feb-11**	**10**	**86**	**-76**
2	**Collection and analysis of data**	**J&R**	**07-feb-11**	**20-maj-11**	**75**	**76**	**-1**
2,1	Market analysis	J&R	07-feb-11	18-mar-11	30	76	-46
2,2	Requirement analysis	J&R	21-mar-11	01-apr-11	10	46	-36
2,3	Propose design system	J&R	04-apr-11	20-maj-11	35	36	-1
3	**Report writing**	**J&R**	**23-maj-11**	**10-jun-11**	**15**	**1**	**14**
3,1	Introduction	J&R	23-maj-11	10-jun-11	15	1	14
3,2	Theoretical background	J&R	23-maj-11	10-jun-11	15	1	14
3,3	Methods and approach	J&R	23-maj-11	10-jun-11	15	1	14
3,4	Results and discussion	J&R	23-maj-11	10-jun-11	15	1	14
3,5	Conclusions and Future work	J&R	23-maj-11	10-jun-11	15	1	14
4	**Master´s thesis presentations**	**J&R**	**10-apr-11**	**20-apr-11**	**8**	**31**	**-23**
5	**Presentation**	**J&R**	**20-maj-11**	**05-jun-11**	**11**	**2**	**9**
5,1	PowerPoint creation	J&R	20-maj-11	01-jun-11	9	2	7
5,2	Preparation for final presentation	J&R	01-jun-11	04-jun-11	3	-8	11
5,3	Preparation for opposition	J&R	20-maj-11	05-jun-11	11	2	9
5,4	Opposition	J&R	20-maj-11	05-jun-11	11	2	9
5,5	Presentation	J&R	06-jun-11	06-jun-11	1	-11	12

Appendix C; Gas and liquid fuel data

Gas and liqued fuel data								
USD → Euro exchange rate	0,70							
Natural BOG price	2,50	USD/mmBTU	Indications from LNGC business					
Forced BOG price	7,74	USD/mmBTU	Indications from LNGC business					
LNG LHV	49,2	MJ/kg						
HFO LHV	40,4	MJ/kg				0,716029758		
Crude oil LHV	42,7	MJ/kg						
MGO LHV	42,7	MJ/kg						
				USD/Mt	USD/MJ	USD/MWh	Euro/MWh	Euro/kWh
LNG (mmBTU → kWh)	0,293	MWh		460	0,011386139	40,99009901	28,529109	0,028529109
HFO	11,2	MWh/Mt						
MDO	11,9	MWh/Mt						
MGO	11,9	MWh/Mt						

Fuel price conversion														
HFO price	485	USD/ton	equal to	12,7	USD/mmBTU	equal to	43,2	USD/MWh	equal to	30,1	Euro/MWh	equal to	337,6	Euro / ton
Crude oil price	460	USD/ton	equal to	11,4	USD/mmBTU	equal to	38,8	USD/MWh	equal to	27,0	Euro/MWh	equal to	320,2	Euro / ton
MGO price	850	USD/ton	equal to	21,0	USD/mmBTU	equal to	71,7	USD/MWh	equal to	49,9	Euro/MWh	equal to	591,6	Euro / ton
LNG price	16,9	USD/mmBTU	equal to	788,1	USD/t	equal to	57,7	USD/MWh	equal to	40,1	Euro/MWh	equal to	548,5	Euro / ton

Bbl to Mt	7,4
USD-EURO	0,7
LHV crude oil (MJ/kg)	40,6
MWh/Mt crude oil	11,3

Crude oil price (USD/bbl)	Crude oil price (USD/Mt)	Crude oil price (Euro/MWh)
50,0	370,0	23,0
60,0	444,0	27,6
70,0	518,0	32,2
80,0	592,0	36,7
90,0	666,0	41,3
100,0	740,0	45,9
110,0	814,0	50,5
120,0	888,0	55,1
130,0	962,0	59,7
140,0	1036,0	64,3
150,0	1110,0	68,9
160,0	1184,0	73,5
165,0	1221,0	75,8
180,0	1332,0	82,7

Appendix D; Permission process

This section of the report accounts for the standard and regulations regarding bunkering and the stakeholders involved in the permission process.

D.1. Things to consider regarding bunkering

Different solutions require different magnitude of investigation to be permitted depending on its component parts and procedures. Therefore it is important for the shipowner to know which bunkering solution that is desired to be permitted. The same applies even at which authorities that is concerned and also identifies the relevant stakeholders. The shipowners have to come with a case to the authorities where there has been a thorough investigation and identification of the risks and how these should be avoided or minimized.

Many issues have to be solved before it can be possible to bunker vessels that have short port times. Unfortunately, there is a gap where regulations and standards for bunkering are not organized yet which make it more difficult to handle these questions.

However, The Swedish Transport Agency who is responsible for operations conducted at sea has given points that have to be investigated before a bunkering procedure can be conducted;

- Risk analysis for the fuel bunkering procedure
- Involved vessels in the bunkering procedure
- Risk analysis that covers the bunker vessel traffic at the port of Gothenburg in relation to other traffic- *SIGGTO's recommendation for shipping traffic and its surroundings should be used for the risk analysis at the prospective shipping traffic and the operation areas*
- Plan for security zones, i.e. Safety distance around the bunker or tank truck

D.2. External conditions

External conditions should be investigated in the area of the bunkering operation. An example might be to examine the conditions to bunker in the urban area of the port of Gothenburg in order to find out where it can be possible to do such operations. Things to investigate in that case are the acceptance from stakeholders, are the safety distance enough, how the surrounding environment will be affected, what impact it will be at nearby activities and is this something that can get a permit granted scope.

D.3. Processes

In the next two paragraphs, permitting processes for environmental permits of building an LNG storage tank and permits for retrofitting of ships to LNG are described. Those processes are important to consider due to the fact that it would probably look similar in the LNG bunkering case.

Environmental permit process

Bunkering of LNG on ships does not exist in Sweden yet so there has not been any environmental permission process developed for this. The planed LNG storage tank in Gothenburg went through an environmental permit process at the county board for a land based fire protection facility which is illustrated in Figure 33. This environmental permit process would look similar for ships if they use a land based LNG storage tanks in their bunkering process. In the law of flammable and explosive goods (SFS 2010:1011) the parliament have decided on how the permit process should be carried out for handling of these types of goods at land which also has to considered (39) (40).

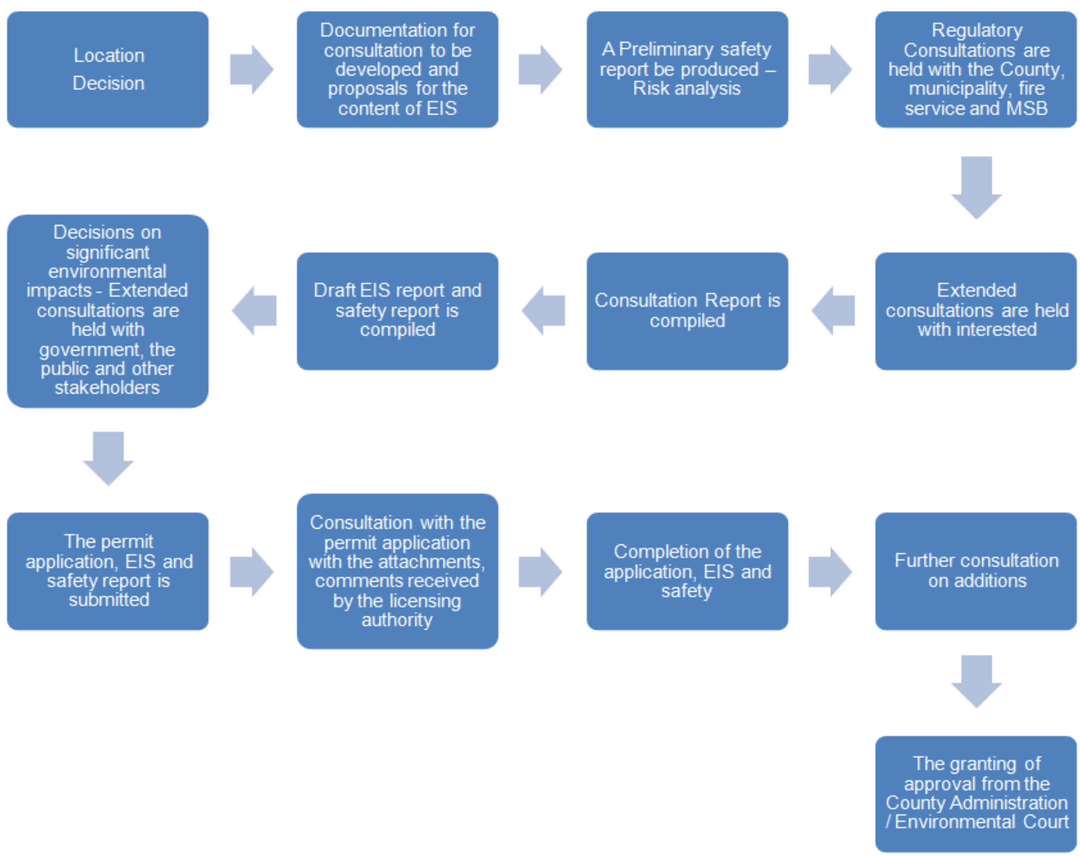


Figure 33 Environmental permission process of building an LNG storage tank.

The process for approval of natural gas as fuel in ships

A report that was written at the spring of 2011 on retrofitting of an existing ship to LNG in operation described the process of how to get permission to do this retrofitting. The process is illustrated in Figure 34 via a block diagram (7).

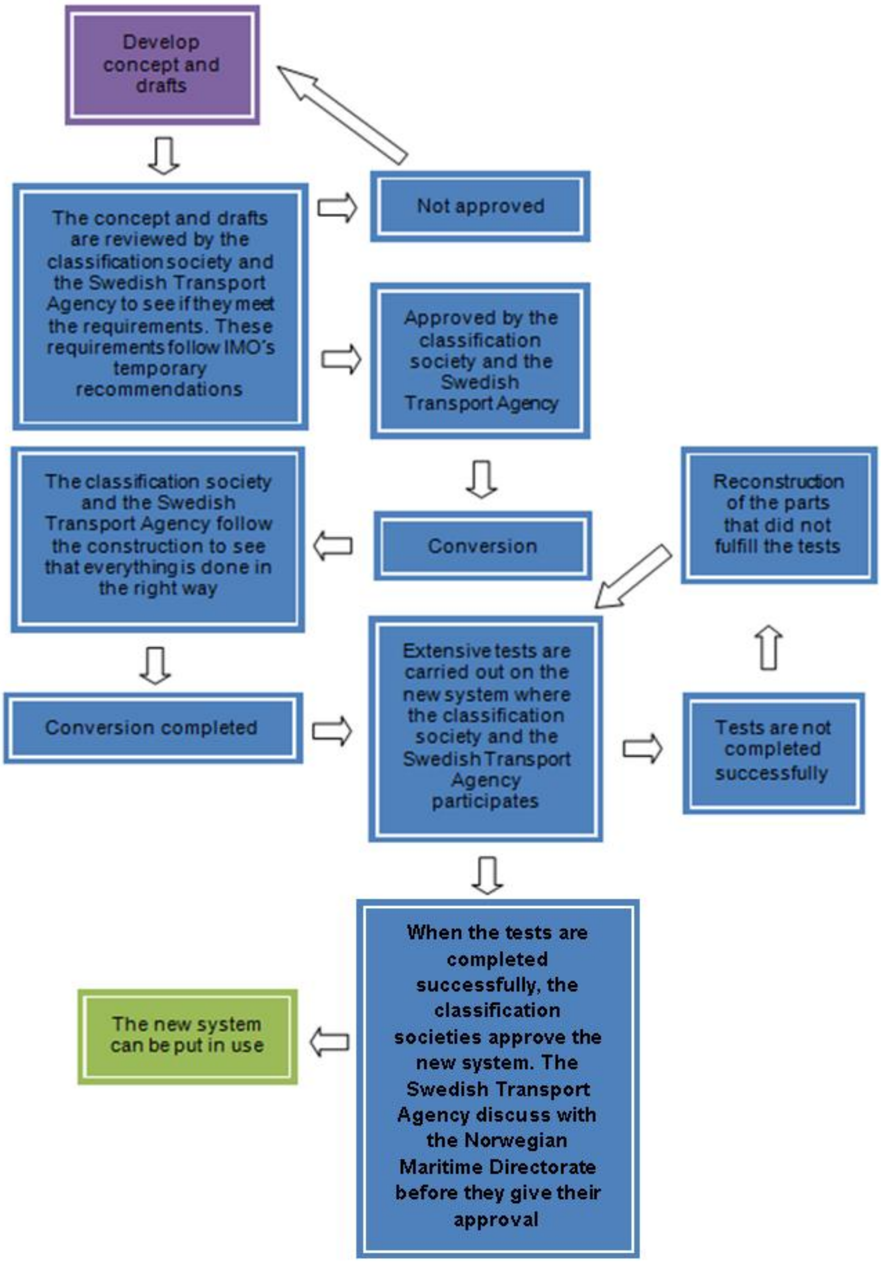


Figure 34 Permission process of retrofitting a ship to LNG in operation.

D.4. Rules

There are a variety of rules and regulations for the LNG users to relate to. Permissions offshore are today given from the Swedish Transport Agency but there is no regulatory framework that is prepared for the bunkering offshore yet, but IMO are working on developing one. Onshore, fallowing points should be considered for transport and manage fuels and the remaining part is for offshore. Note that this may differ from case to case (16) (18) (22) (41).

Onshore

- Law of flammable and explosive goods (SFS 1988:868)
- The law on prevention and mitigation of major chemical accidents (SFS 1999:381)
- Environmental Code (SFS 1998:808)
- Planning and Building Act (SFS 1987:10)
- Law on protection against accident (SFS 2003:778)

Offshore

- **IMO IGC Code** - *The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*
- **IMO IGF Interim guidelines** - *The International Code of Safety for Gas-fuelled Ships*
- **IMDG Code** - *International Maritime Dangerous Goods Code*
- **SIGTTO** - *The Society of International Gas Tanker and Terminal Operators Ltd*
- **DNV** - *Rules for the classification of Gas fuelled engine installations*
- **SOLAS** - *International Convention for the Safety of Life at Sea*

D.5. Standards and guidelines

Right now there are no standards for bunkering from ship to ship or from port to ship. Therefore, today ship-owners instead need to go through a permit process for each nation's flag as they operate within. However, there are guidelines published by the *Society of International Gas Tanker and Terminal Operators Ltd* (SIGTTO) for bunkering ship to ship but those guidelines are focused on large scale LNG transfer but could be considered in this case at many aspects. *The International organization for standardization* (ISO) has also started a group to develop standards for the bunkering procedure and its equipment. These will be posted soon so it will probably not be any major problems for the shipowners of how they should manage this problem. It should also be mentioned that the *"LNG bunkering Ship to Ship"* project that have been carried out through a joint development between Swedish Marine Technology Forum, FKAB Marine Design, Linde Cryo AB, *Det Norske Veritas* (DNV), LNG GOT and White Smoke AB can serve as guideline for bunkering LNG at short time operations.

D.6. Authorities connected to the bunkering process in Sweden

Bunkering LNG is a process that requires well-developed security arrangements, and advanced and reliable technology. Due to that fact, several authorities and agencies are involved to share their opinion and give their permission about the case before starting the management of LNG. Every stakeholder has its own area where they are engaged and influencing. The paragraphs below describe the most essential stakeholders in a permission process of bunkering LNG offshore and permission for construction of LNG plant onshore but other may occur locally (8) (22) (39) (41);

- **The Swedish Transport Agency, Maritime department** - *Formulate regulations offshore, examines and grants permits through inspections at Swedish and foreign vessels sailing in Swedish waters. Work with improvements of maritime safety and environmental influence from recreational boating*

- **Swedish Civil Contingencies Agency (MSB)** - *Responsible for the regulations onshore and determines which activities that are allowed. Also enhance and support society's ability to face and manage accidents and crises*

- **The authority of the port** - *Determine which activity that are allowed in the harbour*

- **The county board** - *Approving authority for environmental permits for the storage of LNG and consultative bodies for environmental water activities, fire protection system and administrators of safety*

- **The municipal authority** - *Control the laws relating to environmental and health compliance and approving authority for flammable materials and consultative bodies for environmental permits for water operations*

- **Environmental court** - *Approving authority for environmental permits for water activities such as construction of new unloading terminal for ships, which require major piling work and change of depth in the water*

- **Environmental Department** - *Work with supervision and monitoring of the environmental status in several areas and is also proactive in environmental issues including submitting opinions and give advice and information*

- **Interested companies, individuals and organisations** - *Should be contacted for consultation on permit application for the activity*

Appendix E; Converting Stena Danica´s consumption of HFO to LNG

- **HFO consumption, Gothenburg to Frederikshavn and back:** 14000 kg
- **Energy content HFO:** 40.4 MJ/kg
- **Energy content LNG:** 49.2 MJ/kg
- **Energy consumption, Gothenburg to Frederikshavn and back:** 14000 kg * 40.4 MJ/kg = 565600 MJ
- **LNG consumption, Gothenburg to Frederikshavn and back:** 565600 MJ / 49.2 MJ/kg = 11495 kg
- **LNG density:** 420 kg/m^3
- **Volume of LNG consumption, Gothenburg to Frederikshavn and back:** 11495 kg / 420 kg/m^3 = 27.4 m^3
- **Safety factor:** 1.3
- **Total LNG consumption, Gothenburg to Frederikshavn and back:** 27.4 m^3 * 1.3 = 35.6 m^3

Appendix F; LNG price from AGA Nynäshamn

Vad skulle det kosta per leverans av LNG ca 107 m³ (Lastbil + gods + tankoperatör)?
- AGAs största fordon, bil och släp med brutto tankvolym om 80 m^3, har en pay load på 25,6 ton LNG

- Transportkostnaden är beräknad för sträckan Nynäshamn till Göteborg

Pris transport: SEK 810 per ton

LNG: SEK 7 450 per ton

Totalt inkl frakt: SEK 8 260 per ton (602,90 SEK/MWh berknat med ett typiskt NCV om 13,7 MW/ton)

Ovanstående priser gäller i prisnivå 1 april 2011.

Vad skulle enbart 107 m^3 kosta om Stena bidrar själva med tankbil och tankoperatör?
LNG: SEK 7 450 per ton

Appendix G; Calculations of what Viking Line are willing to pay for LNG

- Bunker world, Rotterdam 672 $/mt 14/4 - 2011

- Lower heating value, HFO= 40.4 MJ/Kg

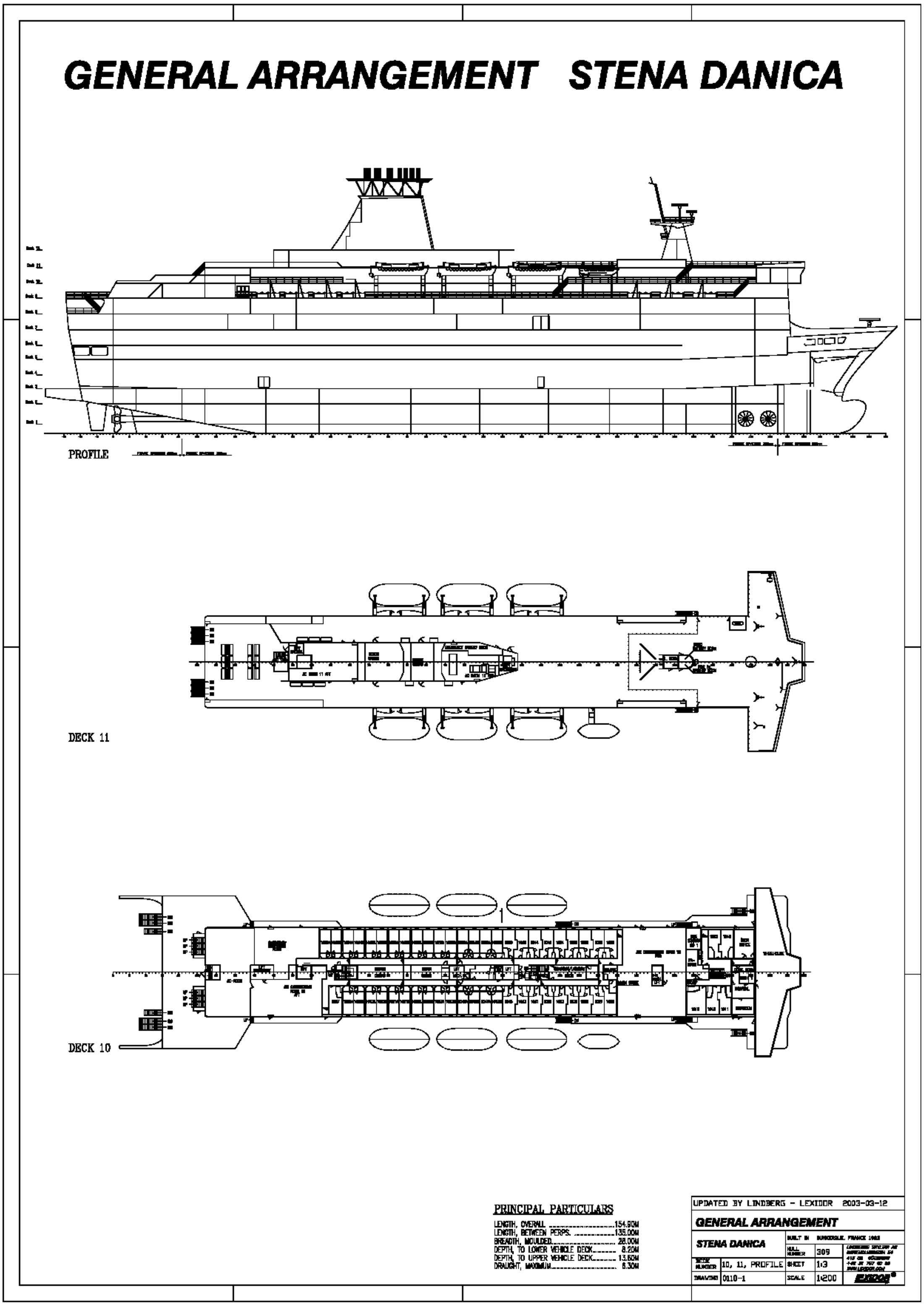
- 1 KWh = 3.6 MJ

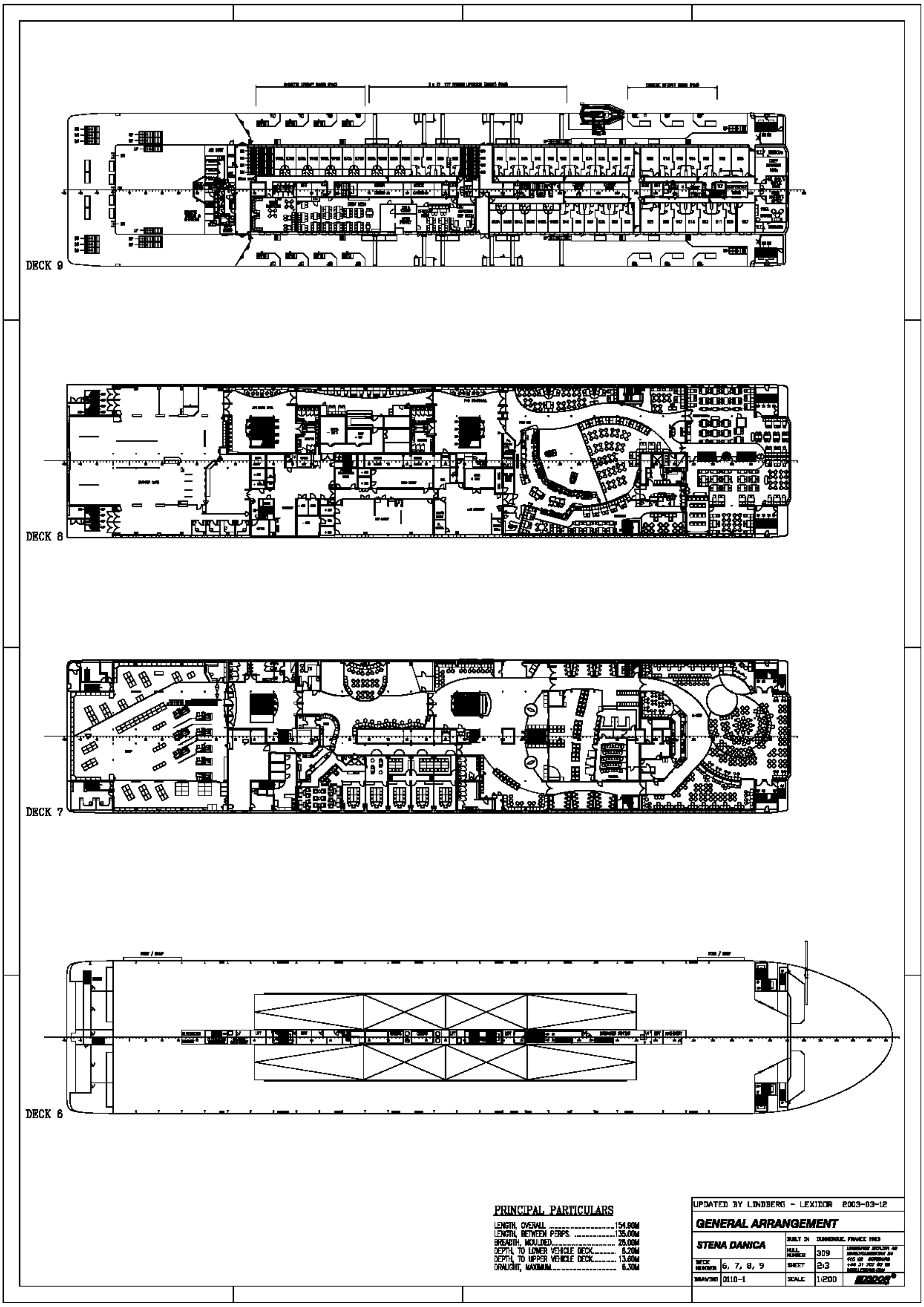
- 1 $ = 0.6894 € , Citibank N.A 14/4 - 2011

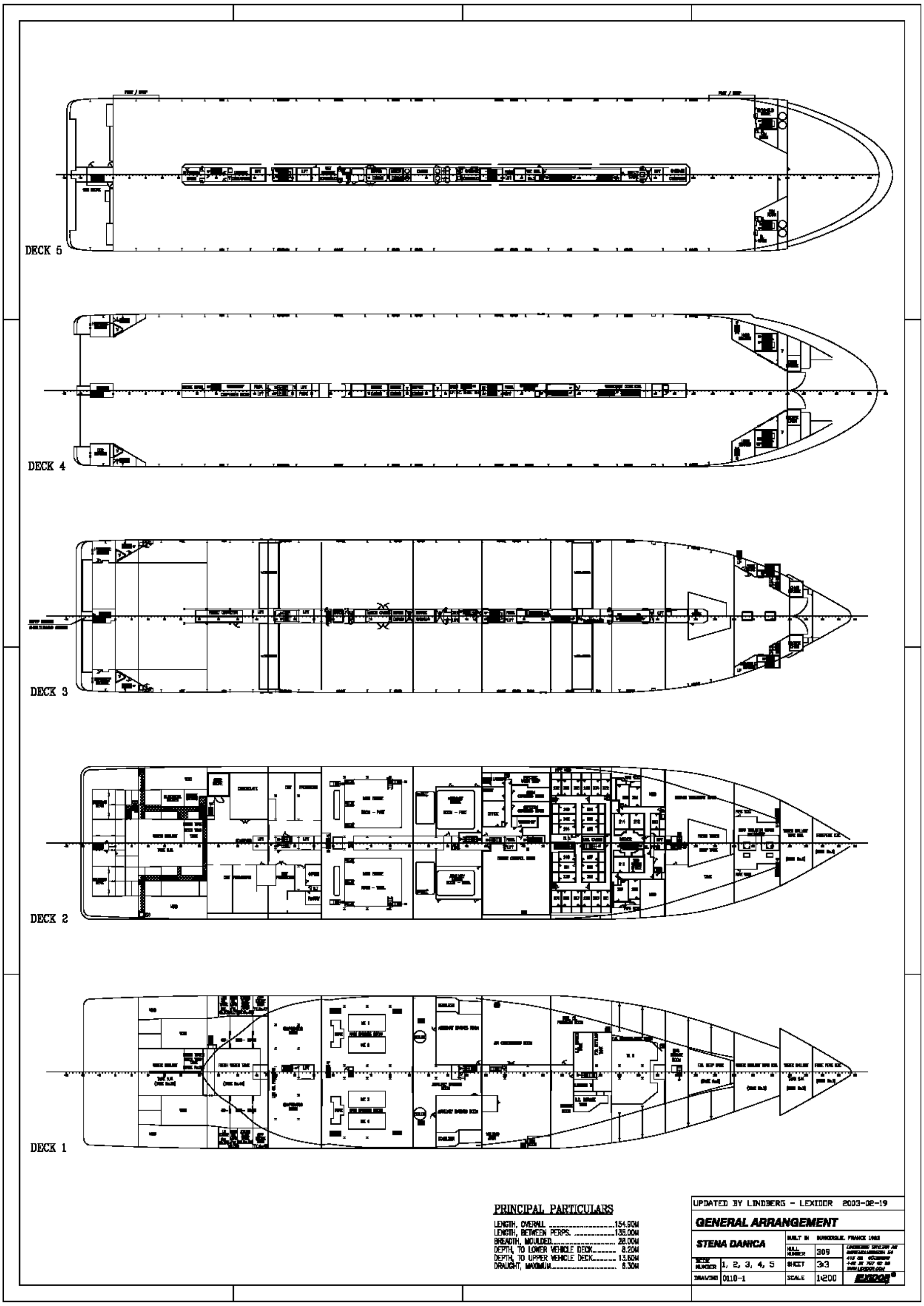
(A) 40.4 MJ/KG * 1000 Kg = 40400 MJ
(B) 40400 MJ/ton * (1/3.6) KWh/MJ = 11.222 MWh/ton
(C) 672 $/ton / 11.222 MWh/ton = 59.88 $/MWh
(D) 59.88 $/MWh * (0.6894 € / 1 $) = 41.28 €/MWh

Viking line is willing to pay 40 % above that price of HFO for LNG, 41.28 €/MWh * 1.4 = 57.79 €/MWh.

Appendix H; Stena Danica General Arrangement




DECK 9
DECK 8
DECK 7
DECK 6
PRINCIPAL PARTICULARS
LENGTH, OVERALL 154.90M
LENGTH, BETWEEN PERPS. 135.00M
BREADTH, MOULDED........................ 28.00M
DEPTH, TO LOWER VEHICLE DECK........ 8.20M
DEPTH, TO UPPER VEHICLE DECK........ 13.60M
DRAUGHT, MAXIMUM......................... 6.30M
UPDATED BY LINDBERG - LEXIDOR 2003-03-12
GENERAL ARRANGEMENT
STENA DANICA
HULL NUMBER 309
DECK NUMBER 6, 7, 8, 9
SHEET 2:3
DRAWING 0110-1
SCALE 1:200


DECK 5
DECK 4
DECK 3
DECK 2
DECK 1
PRINCIPAL PARTICULARS
LENGTH, OVERALL 154.90M
LENGTH, BETWEEN PERPS. 135.00M
BREADTH, MOULDED.....................28.00M
DEPTH, TO LOWER VEHICLE DECK........ 8.20M
DEPTH, TO UPPER VEHICLE DECK........ 13.60M
DRAUGHT, MAXIMUM.................... 6.30M
UPDATED BY LINDBERG - LEXIDOR 2003-02-19
GENERAL ARRANGEMENT
STENA DANICA
HULL NUMBER 309
1, 2, 3, 4, 5
SHEET 3:3
DRAWING 0110-1
SCALE 1:200

Appendix I; Engine technology

The coming emission targets in the ECA region will boost the use of more environmental friendly fuels. The shipyards must reduce their emissions drastically to continue to operate in these areas. To be able to use LNG as fuel, the engines have to be retrofitted or replaced. Wärtsilä has three different types of engines technologies that could run at LNG. The DF engine is a Dual-Fuel engine with otto combustion, SG engine is a Spark-Ignited engine with otto combustion and the GD engine is a Gas-Diesel engine with diesel combustion; see Figure 35.

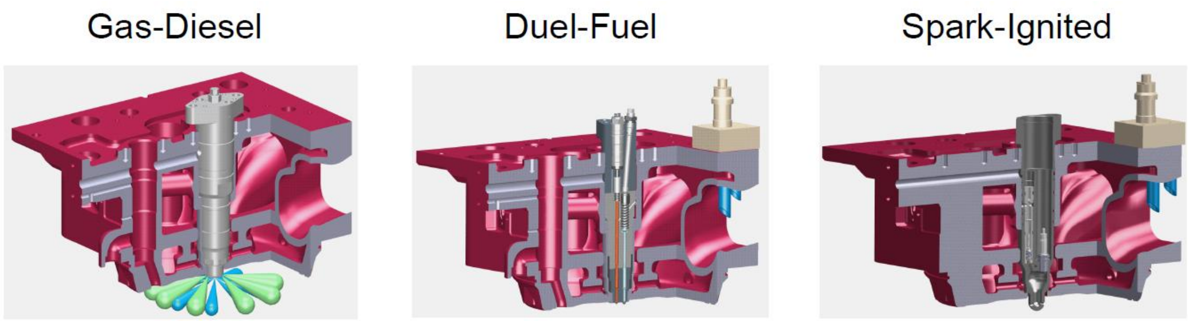


Figure 35 Gas-Diesel, Duel-Fuel and Spark-Ignited engines **(16)**.

Both the DF and SG engines meet the coming regulations in the Emission Control Area. By using a *Selective Catalytic Reduction* (SCR) or *Exhaust Gas Recirculation* (EGR) also the GD engine is potential alternative to use in this region. This engines will reduce the emissions approximately up to 25 % lower CO2, 85 % lower NOx and particularly no SOx emissions. Furthermore the particulate emissions will be reduced up to around 95 % (16).

I.1. Wärtsilä 34DF

Wärtsilä 34DF is a low pressure dual fuel engine with otto combustion; see Figure 36. It is the most common type of marine engine that Wärtsilä´s customer use when they want an engine that can be driven at LNG. It could be run on either LNG or CNG and is major converted by diesel engines. Less than 1% pilot fuel (diesel) is needed at full load and does also satisfy the requirements for the NOx emissions to fulfil the Tier III level (16).

How the DF engine works

The Dual-Fuel engine utilizes a lean burned combustion process when operating on gas. The gas is mixed with air before the intake valves during the air intake period. After the compression phase the gas-air mixture is ignited by a small amount of liquid pilot fuel. This pilot fuel is pressurized and feed into the cylinders by a small common rail system. Combustion is fast and after the working phase the exhaust gas valves open and the cylinder is empty of the exhaust gases. The inlet air valve opens when the exhaust gas valves close and the process starts again. The Dual-Fuel engine is also equipped with a back up fuel system. This is a normal diesel process with cam shaft operated liquid fuel pumps. The pumps run in parallel with the process and work as s standby. Gas and pilot injection is not in use during liquid fuel operation. The liquid fuel operation process is the same as the conventional diesel process (16).

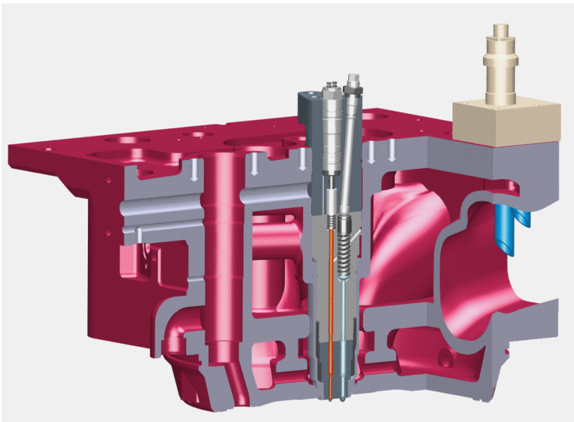


Figure 36 DF engine **(16)**.

In the table below there are some technical data specified; Table 11.

Table 11 Technical data 34DF **(16)**.

	Marine Engines	Power Engines
Cylinder bore [mm]	340	340
Piston stroke [mm]	400	400
Engine speed [rpm]	720 and 750	720 and 750
Piston speed [m/s]	9.6 / 10.0	9.6 / 10.0
Mean effective pressure [bar]	20 / 19.8	20 / 19.8
Output per cylinder [kW]	435 / 450	435 / 450
Available cylinder configurations	6L, 9L, 12V and 16V	9L, 16V and 20V

Advantages and disadvantages for the technology;

Advantages

- Tier III solution
- Higher ignition energy than spark plug but prechamber ignition – booster
- High efficiency in gas mode

Disadvantage

- Fuel sensitive (knocking), Methane number (MN) > 70 → no derating
- High Total Hydro Carbon (THC) and Carbon Monoxide (CO)
- Lower load acceptance (16).

I.2. Wärtsilä 34SG

Wärtsilä 34SG is a low pressure mono fuel engine with otto combustion; see Figure 37. It could be run on either LNG or CNG gas and is major converted by diesel engines. Another advantage of this technique is that the engine does not need any pilot fuel and does also satisfy the requirements for the NOx emissions to fulfil the Tier III level (16).

This engine type has a disadvantage in terms of reliability. It can form something called COX on the spark plugs. COX is a coating that forms on the spark plugs and reduce its ignition capability. To counteract from this type of coating the spark plugs must be replaced periodically. The engine rooms on the vessels are often sparsely designed which makes it difficult to replace the spark plugs. This means that this type of engine is more suitable on land-based power plants where the engine rooms are not that sparsely designed. On the other hand, the COX is just a technical limit and with further development this issue could be solved.

How the SG engine works

The SG engines are spark ignited leaned burned engines. In this process the gas is mixed with the air before the inlet valves and the gas-air mixture is compressed during the compression phase. During the intake period, gas is also fed into a small pre chamber where the gas mixture is rich compared to the gas in the cylinder. At the end of the compression phase the air mixture in the pre chamber is ignited by a spark plug. The flames from the nozzle at the pre chamber ignite the gas-air mixture in the whole cylinder and the combustion is fast. After the working phase the cylinder is empty and process starts again (16).

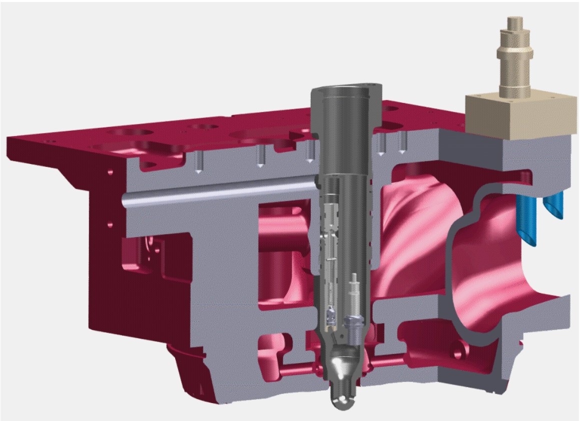


Figure 37 SG engine **(16)**.

In the table below there are some technical data specified; Table 12.

Table 12 Technical data W34SG **(16)**.

	Power Plant engines W34SGC-CD	Power Plant engines W34SGC-2
Cylinder bore	340 mm	340 mm
Piston stroke	400 mm	400 mm
Engine speed	525...750 rpm	720/750 rpm
Piston speed	9.6/10 m/s	9.6/10 m/s
Mean effective pressure	19.8 bar	22 bar
Output per cylinder	315...450 kW	480/500 kW
Available cylinder configurations	9L, 16V, 20V	9L, 16V, 20V

Advantages and disadvantages for the technology;

Advantages

- Tier III solution
- No additional fuel beside gas
- High efficiency

Disadvantage

- Fuel sensitive (knocking), *Methane number* (MN) > 70 → no derating
- High *Total Hydro Carbon* (THC) and *Carbon Monoxide* (CO)

- Lower load acceptance
- No back-up fuel (16).

I.3. Wärtsilä W32GD

Wärtsilä W32GD is a high pressure dual fuel engine with diesel combustion; see Figure 38. Its run on LNG and is limited converted by diesel engines. It is possible by direct drive of propellers, furthermore 5% pilot fuel (diesel) is needed. Wärtsilä W32GD does not satisfy the requirements for the NOx emissions to fulfil the Tier III level (16).

To satisfy this requirement it is possible to install a *Selective Catalythic Reduction* (SCR) or *Exhaust Gas Recirculation* (EGR). SCR can provide a NOx reduction of about 90%. It is a technology that cleans the exhaust gases from NOx by adding ammonia or urea in to the exhaust gases. By using the heat from the exhaust gas, a chemical reaction that undergoes inside the catalytic. The nitrogen oxide converts in to nitrogen and water. EGR can provide a NOx reduction of about 70%. It is a technology based on that parts of the exhaust diversion into a ceramic particular filter that purify the exhaust gases from soot. Furthermore the cleaned exhaust gases are led to a cooler which cools its temperature. After the gases have been passing the cooler, they are led to a secondary filter and then through a control valve into the engine. By add the cooled gases, the oxygen level will be lowered down and the combustion temperature will decrease. The method works for fuel up to a sulfur content of 0.2%. There is also a technique called scrubber which cleans fuel from sulfur and soot, but it is not needed in the cases where the levels of sulfur in the fuel are very low (42).

How the GD engine works

The Gas-Diesel process has three possible operating modes; gas, liquid fuel and fuel sharing. In gas mode the gas is injected at high pressure after the pilot fuel and is ignited by the flame from the pilot fuel injection. The amount of pilot fuel is equivalent to approximately 5% to the fuel energy input at fuel engine load. The Gas-Diesel engine can be switched over instantly to liquid fuel mode operation. The liquid fuel can be light fuel oil, heavy fuel oil or crude oil. In this case the process is the same as the conventional diesel process. In fuel sharing mode the ratio between liquid and gas fuel amount can be controlled and varied during operation. The operation window for the fuel sharing mode is 35- 90 percent load and the gas liquid fuel ratio can vary from 80:20 to 15:85. The Gas-Diesel process can tolerate large variation in the gas quality and is especially suitable for non pipeline quality gas such as associated gas in the oil field (16).

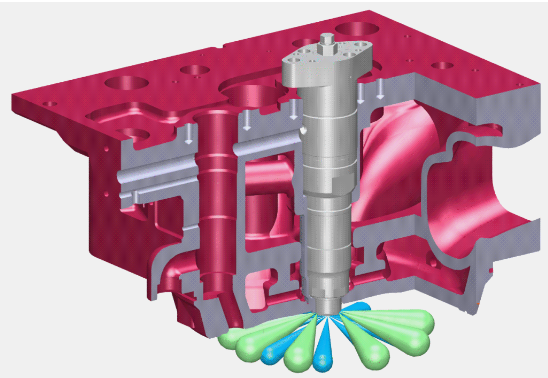


Figure 38 GD engine **(16)**.

In the table below there are some technical data specified; Table 13.

Table 13 Technical data W32GD **(16)**.

Power Plant engines	
Cylinder bore	320 mm
Piston stroke	400 mm
Engine speed	720 - 750 rpm
Piston speed	9.6 - 10 m/s
Mean effective pressure	22.9 - 23.3 bar
Output per cylinder	450/460 kW
Available cylinder configurations	6L, 7L, 8L, 9L, 12V, 16V, 18V, 20V

Advantages and disadvantages for the technology;

Advantages

- Not knock sensitive
- Low *Total Hydro Carbon* (THC) and *Carbon Monoxide* (CO)
- High load acceptance

Disadvantage

- Do not meet the emission levels in Tier III standard (16).