LNG Bunkering Infrastructure Solution and Pilot actions for Ships operating on the Motorway of the Baltic Sea

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Method
## Abbreviations

<table>
<thead>
<tr>
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<th>Description</th>
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<tr>
<td>DF</td>
<td>Dual Fuel</td>
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<tr>
<td>DWT</td>
<td>Deadweight</td>
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<td>EEDI</td>
<td>Energy Efficiency Design Index</td>
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<tr>
<td>ESD</td>
<td>Emergency Shut Down</td>
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<tr>
<td>GHG</td>
<td>Green House Gases</td>
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<td>GVU</td>
<td>Gas valve unit</td>
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<tr>
<td>HAZID</td>
<td>Hazard Identification</td>
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<tr>
<td>HAZOP</td>
<td>Hazard and Operability assessments</td>
</tr>
<tr>
<td>HFO</td>
<td>Heavy Fuel Oil</td>
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<tr>
<td>IACS</td>
<td>International Association of Classification Societies</td>
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<tr>
<td>IMO</td>
<td>International Maritime Organisation</td>
</tr>
<tr>
<td>INEA</td>
<td>Innovation and Network Executive Agency</td>
</tr>
<tr>
<td>ISM</td>
<td>International Ship Management</td>
</tr>
<tr>
<td>ISPS</td>
<td>International Ship and Port Safety</td>
</tr>
<tr>
<td>JIP</td>
<td>Joint Industry Project</td>
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<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>LSR</td>
<td>LNG Sea River</td>
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<tr>
<td>MARPOL</td>
<td>Marine Pollution Convention</td>
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<tr>
<td>MCR</td>
<td>Maximum Continuous Rating</td>
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<tr>
<td>MDO</td>
<td>Marine Diesel Oil</td>
</tr>
<tr>
<td>MEPC</td>
<td>The Marine Environment Protection Committee</td>
</tr>
<tr>
<td>MGO</td>
<td>Marine Gas Oil</td>
</tr>
<tr>
<td>NCR</td>
<td>Nominal Continuous Rating</td>
</tr>
<tr>
<td>NECA</td>
<td>Nitrogen Emission Controlled Area</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>SCR</td>
<td>Selective Catalyst Reduction</td>
</tr>
<tr>
<td>SECA</td>
<td>Sulphur Emission Controlled Area</td>
</tr>
<tr>
<td>SSD&amp;B</td>
<td>Small Scale distribution and bunkering</td>
</tr>
<tr>
<td>TEN-T</td>
<td>Trans-European Transport Networks</td>
</tr>
<tr>
<td>VOLY</td>
<td>Value Of Life Year lost</td>
</tr>
<tr>
<td>VSL</td>
<td>Value of Statistical Life</td>
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<tr>
<td>ZVT</td>
<td>Zero Vision Tool</td>
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In this section the project in general and the activity on which this report is based is introduced. The background, context and content of the project as well as the activity at hand is described. This section is concluded with a report outline.

1. Introduction

The project “LNG Bunkering Infrastructure Solution and Pilot actions for Ships operating on the Motorway of the Baltic Sea”, Pilot LNG for short, is a TEN-T co-financed Action undertaken by 13 different companies in four EU member states. The Action is a part of a Global Project in which several other concurrent, previous and future actions are included. The entities participating in the capacity of Beneficiaries range from shipping companies, ship yards and class societies to shippers, maritime consultancy, research and development companies and trade organizations. The total original budget of Pilot LNG was €74.6 Million of which €23.1 Million was accepted for TEN-T co-financing. The duration of this Action has been from 1 January 2012 to 31 December 2015.

The primary reason for initiating the Global Project and its comprising Actions was the enactment of reduction of the maximum allowable maritime fuel sulphur content in the Sulphur Emission Control Area (SECA) in the Baltic and North seas and the English Channel (Figure 1.1). This Actions aims to contribute to addressing the challenges posed following the heightened SECA requirements through Works, Studies and dissemination. The Works both ensure that necessary system components will be developed and implanted at the same time as it contributes to development of technical, operational and regulatory solutions. The Studies and dissemination activities compile, evaluate and publish the results facilitating for others to follow, thereby maximising the EU added value.

Aside from the 13 Beneficiaries, dozens of other organizations have been involved and conducted relevant work as well as dozens of supporters and followers of the project. In order to be able to facilitate effective coordination, cooperation and dissemination a collaboration platform and method, Zero Vision Tool (ZVT), was employed. The project has been organised and managed using this methodology, and the platform will continue to fulfil a roll in disseminating the results even after the completion of the Action by 31 December of 2015.

The Action is organised in eight different Activities, most of which contain several sub-activities. The first six Activities are works that aim to develop and produce necessary components of the infrastructure required for using liquefied natural gas (LNG) as a maritime fuel. The final Activity is put in place for project management and dissemination. Activity 7, which is classified as a study, is tasked with the compilation and evaluation of the results of the Action.

Activity 7 consists, beside the task of compiling the results, of 4 sub-activities that are created in order to evaluate: 1) LNG as a maritime fuel from a technical and operational perspective, 2) environmental performance of LNG technology, 3) the compiled costs when connected with the use of LNG as fuel from and possible savings and 4) invest and suggest a way forward if the need for another financial mechanism has to be established to support followers. This will be based on the results from the other activities. In addition, the Activity 7 report is to provide a “best practice” for similar projects in the future.

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1 EU Contract No. 2012-EU-21009-M.
In this report, the outcome of Activity 7 is delivered. This report, upon its approval by the Steering Committee (SC), will serve as the verification for the achievement of milestones 14 and 15 as per the Commission Decision of 18.12.2013, 2012-EU-21009-M.

This section of the report continues with a more detailed description of the Global Project, the Action, Activities and other relevant Actions in the Global Project. This section is concluded with a report outline which is to serve as a supporting guideline for the reader.

1.1 Background and motivation for the project

The Marine Environment Protection Committee (MEPC) of the International Maritime Organisation (IMO) unanimously adopted the revised Annex VI to MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships) on 10 October 2008, which places restrictions on nitrogen and sulphur oxides emissions from ship traffic. Emissions of particulate matter from shipping should be reduced by lowering the sulphur content in fuels. The new Annex enters into force on 1 July 2010. The sulphur content of fuel will fall in the special areas (SECA = Sulphur Emission Control Area), which are the Baltic Sea, the North Sea and the English Channel, from 1.5% to 1% from 1 July 2010, and to 0.1% from 1 January 2015. The SECA areas in Europe are the pioneers globally, as worldwide the highest permitted sulphur content of fuel will fall, as from 1 January 2012, from 4.5% to 3.5%, and to 0.5% from 1 January 2020.

Different technical solutions have been identified in order to meet the new restrictions, among others the use of LNG as a fuel for shipping. Others are the use of marine gas oil (MGO), marine diesel oil (MDO), scrubbers or use of renewable energy.

Ship owners are challenged by the new MARPOL legislation and the motivation of the project is to support the ship owners in taking the next steps towards a greener shipping industry.

1.2 The Global Project

Stricter emission regulations in North European waters from 2015 onwards will add considerable costs to shipping. The aim of the Global Project is to find solutions to meet the stricter legislation that are safe, environmentally sustainable, technically viable and cost efficient. This will support the development of a strong and competitive shipping sector and contribute to the successful implementation of the Motorways of the Sea priority project no 21 (as of annex III of the TEN Guidelines) in the Baltic Sea region.

In 2015 the stricter sulphur legislation in the Sulphur Emission Control Area (SECA) reducing allowed Sulphur emissions by 90% will enter into force. The possible ways to meet the challenge is to either replace the fuel or to clean the exhaust gases on board the vessels. To decide which method to use is a complex process, especially for existing vessels.

In 2015 the stricter sulphur legislation in the Sulphur Emission Control Area (SECA) reducing allowed Sulphur emissions by 90% will enter into force. The possible ways to meet the challenge is to either replace the fuel or to clean the exhaust gases on board the vessels. To decide which method to use is a complex process, especially for existing vessels.
The new regulations will affect a large number of vessels. In 2011 about 7500 ship individuals with an IMO number visited the Baltic Sea (Source: Emissions from Baltic Sea shipping in 2011, Baltic Sea Environment Factsheet, www.helcom.fi) and at any given time about 2000 vessels are within the Baltic Sea area. The Global Project will assist in finding the best strategy for fulfilling the new regulations for this fleet.

The fastest way, and the one mainly used in port today, is to use MDO or MGO (Marine Diesel/Gas Oil) with a maximum Sulphur content of 0.1%. The additional cost of this fuel is, however, high and using this solution in the larger SECA area will mean a large increase in operational cost.

Three alternative solutions, for entire transport systems, have been identified;

- Methanol
- LNG (Liquefied Natural Gas)
- Scrubbers; Systems to clean the exhaust from vessels running on HFO (Heavy Fuel Oil) with higher Sulphur content

The Global Project consists of, among others, three standalone Actions, where transport system Pilots for each of these identified solutions is implemented by combining different industrial projects (Joint Industry Projects, JIP, see below) all using the ZVT collaboration method and platform.

The lessons learned from the Pilots will support other stakeholders (followers), who are not actively participating in this first phase, in their investment decisions. When using the ZVT method the JIPs and Pilots have to consist of stakeholders from different trades, such as ship-owners, ports, terminal operators, gas fuel suppliers, equipment providers, new building and repair yards, classification society, authorities etc. who sees a need to collaborate in order to find solutions and share knowledge. This is also true for Pilot LNG. The reason is that each JIP needs to find common ground between the trades in the issues raised. Issues that cannot be resolved by the JIPs, such as regulation challenges or other, are lifted to the reference group ZVT REF, comprising agencies and administrations, in order to find workable and sustainable solutions.

ZVT is used when the Global project is launched, planned and executed, through the extensive network and knowledge among partners.

The goal of this Action is to establish a LNG supply and infrastructure solution. The Action will work with the full chain of LNG as a fuel, from LNG infrastructure in form of terminals and feeder vessels, via bunker vessels to the users in form of vessels operating in the Baltic area.

1.3 Description of Action – Pilot LNG

LNG is an attractive alternative fuel for the Shipping Community, especially in Areas with emission regulations. With LNG as fuel the SO\textsubscript{x} emissions are reduced well below SECA rules. At the same time greenhouse gas (GHG) emissions are reduced by at least 10%, NO\textsubscript{x} emissions can fulfil IMO Tier III levels (80% reduction) and PM (Particulate Matter) emissions are lowered by at least 90% compared to HFO (heavy fuel oil) operation. By using LNG as fuel vessels will be able to fulfil the regulations in SECA and NECA (Nitrogen Emission Control) areas, and the reduced CO\textsubscript{2} emissions will contribute to a lower EEDI (Energy Efficiency Design Index) value.
The Action classifies as project of common interest and is a combination of works and Pilot actions which include activities which have a wider benefit for shipping (article 13 of the TEN Guidelines, paragraph 5(c)) by introducing LNG as a marine fuel to help achieve IMO MARPOL Annex IV requirements Sulphur Emission Controls Areas in the Baltic Sea.

The goals of this Action; to implement a LNG bunker supply infrastructure for use of LNG, incl.:

- building a connection from a LNG terminal to jetty to facilitate loading to bunker vessel and/or vessels operating on LNG (Activity 1)
- building a bunker vessel with open access to commercial end-users on non-discriminatory basis (Activity 2)
- LNG feeder vessel with innovative, integrated LNG tank design for better utilization of cargo volume area (Activity 3)
- LNG tanker vessel using LNG as fuel in a low speed 2-stroke Main Engine (Activity 4)
- Optimizing the arrangement of LNG tanks, piping etc. to minimize cargo capacity loss on a Dry Cargo vessel operating in inland waterways and in the Baltic Sea (Activity 5)
- Conversion of tanker vessel using LNG as fuel (main and auxiliary engines). Conversion of auxiliary engine enables installation of LNG tanks with reduced isolation (Activity 6)

The LNG terminal is located at the Port of Brofjorden, Lysekil at the west coast of Sweden (See Figure 1.2). The real life evaluation will be conducted by installing and operating the technologies in full scale in vessels operating the in the Baltic and in the North Sea.

Figure 1.2 Location of LNG terminal and main operating areas of participating vessels
LNG will be provided to any commercial ship-owner/operator from a bunker vessel primarily in the Gothenburg/Skaw area. Investments in the LNG port infrastructure and in LNG fuelled ships are done simultaneously, and there will be a coordinated supply and demand in time. This is of great importance to secure the investments by the stakeholders. In Table 1-1 a summary of all the activities including a short description of activities and activity partners/stakeholders are presented. Activities 1-6 corresponds to individual JIPs which are works or studies via pilot action. Activities 7 and 8 pertain to compilation and evaluation of the results of the project in its entirety, i.e. Pilot LNG as a whole and project management and dissemination. This means that the partners and stakeholders of all other activities cooperated and contribute to these two activities. The completion verification for activities 1-6 are physical infrastructural components such as vessels or buildings where as activities 7 and 8 are verified through reports.

<table>
<thead>
<tr>
<th>JIP</th>
<th>Task/Funding</th>
<th>Partners</th>
</tr>
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<tbody>
<tr>
<td>1. SKANBUNK</td>
<td>Building a connection from the LNG terminal to the jetty in the Port of Brofjorden</td>
<td>Skangas, Preem, SSPA and SSA</td>
</tr>
<tr>
<td>2. FLEXI</td>
<td>Building a LNG feeder vessel with an innovative cargo tank design to support the distribution of LNG</td>
<td>Sirius Shipping, Skangas, Preem, SSPA and SSA</td>
</tr>
<tr>
<td>3. SSD&amp;B</td>
<td>Small Scale distribution and bunkering. To design, build and operate a bunker vessel operating from Brofjorden LNG terminal</td>
<td>Donsötank, SSPA and SSA</td>
</tr>
<tr>
<td>4. EVO</td>
<td>New Building of tanker vessel using LNG as fuel in a low speed 2-stroke main engine</td>
<td>Sirius Shipping, Preem, SSPA and SSA</td>
</tr>
<tr>
<td>5. LNG SEA RIVER (LSR)</td>
<td>Construction of LNG-fuelled sea going dry cargo vessel suitable for inland waterways</td>
<td>Erik Thun AB, Lloyd’s Register, Ferus Smit, SSPA and SSA</td>
</tr>
<tr>
<td>6. LNG CONV</td>
<td>Conversion of a tanker into LNG/HFO dual fuel propulsion</td>
<td>Furetank, Öresund Drydocks, FKAB, Bureau Veritas, SSPA and SSA</td>
</tr>
<tr>
<td>7. Compilation and evaluation of results</td>
<td>Compilation and evaluation of project results and suggesting schemes for large scale financing of more environmentally-friendly systems (not a JIP)</td>
<td>ALL</td>
</tr>
<tr>
<td>8. Project management and dissemination</td>
<td>Project management and dissemination of results (not a JIP)</td>
<td>ALL</td>
</tr>
</tbody>
</table>

Table 1-1 JIPs, activities and stakeholder included in Pilot LNG
1.4 Other relevant Actions in the Global Project

Due to the introduction of the Sulphur Emissions Control Area (SECA), several EU funded projects have been initiated aiming to find solutions for adapting technologies and infrastructure for the shipping industry. The text below gives some indications on projects that have been identified in order to provide information on other linked projects when it comes to sulphur emission reduction.

Regarding LNG as an alternative fuel the following projects can be mentioned:

- The first is the “Feasibility study for an LNG filling station infrastructure and test of recommendation” (2010-EU-21112-S), coordinated by the Danish Maritime Authority.
- The second study focuses on the process of developing a network of LNG bunker filling stations in the SECA area in a harmonized manner, the “LNG in Baltic Sea Ports” (2011-EU-21005-S), coordinated by Baltic Port Organization.
- The third, the LNG infrastructure project “Make a Difference”, funded by TEN-T (2011-EU-92079-S), aims at finding suitable and feasible LNG solutions on-board ships and to harmonize these solutions with the ports and the LNG suppliers. (also a JIP using the ZVT method)
- The COSTA (2011-EU-21007-S) Action aims at developing framework conditions for the use of LNG for ships in the Mediterranean, Atlantic Ocean and Black Sea areas. It will result in preparing an LNG Masterplan for short sea shipping between the Mediterranean Sea and North Atlantic Ocean as well as the Deep Sea cruising in the North Atlantic Ocean towards the Azores and the Madeira Island.
- The work will also be coordinated and harmonized with a project for a large multimodal LNG import terminal project in the north of Finland, the MangaLNG project, led by Outokumpu Oyj together with other industrial companies in the region. The BothniaLNG project builds on industrial MangaLNG investment and supports studies and direct investments in the area to set up an LNG bunkering and multimodal distribution network by early 2016.
- The TEN-T project LNG in Gothenburg

Important to mention is that we have a close cooperation with the other Pilots and JIPs using the ZVT method: Pilot Methanol Pilot Scrubber

1.5 Report outline

The report is organized according to the following structure:

Section 2, Project organisation and management: In this section the project organisation and management are presented, this includes a short description of all the partners and their respective roles and responsibilities as well as a presentation of the collaboration platform Zero Vision Tool (ZVT).

Section 3, Implementation of Activities: All the JIPs and their corresponding activities included in this action are presented in detail in this section. This includes a description of the implementation of the activities including deviation reports and explanation for terminated activities.
Section 4, Technical and operational evaluation of using LNG as Fuel: In this section the use of LNG as maritime fuel is evaluated with respect to technical and operational performance. Also issues regarding risk are presented here. The main focus of the evaluation is the implementation of the activities. This also serves as the basis for the best practice in this regard.

Section 5, Environmental evaluation of LNG technology: The environmental performance of the new built and converted vessels are presented in this section. In the case of the conversion, the comparison is made with the same vessel before conversion to LNG propulsion. For the new builds, the new vessel is compared to a references vessel that runs on MGO.

Section 6, Financial evaluation of using LNG as fuel: The financial aspects of using LNG as fuel is described in this chapter.

Section 7, The need for a financial mechanism for followers: The motivation for providing public financial support for the project at hand is explained in this section. The section is concluded by making a case for continued support for followers. Some suggestion regarding the setup of the financial mechanisms are presented.
In this section the project organisation and management are presented, this includes a short description of all the partners and their respective roles and responsibilities as well as a presentation of the collaboration platform Zero Vision Tool (ZVT).

2. Project organisation and management

The Action is implemented using ZVT methodology and its management is allocated to activity 8. In the following, the partners and their roles and responsibilities are presented. In addition, the ZVT methodology is elaborated on. Finally, the project management procedure and protocols are presented. For more detail, the reader is referred to the Strategic Action Plan (SAP) and the Project handbook.

2.1 Presentation of project partners

The Pilot LNG project contains 8 activities and a number of sub-activities, and 19 milestones according to Commission Decision the Strategic Action Plan (SAP). These are grouped in a number of activity work packages each lead by different activity leaders.

![Organisational chart for Pilot LNG](image)

The participating partners are presented here below; logos are shown under each activity in the Figure 2.1 above. The project partners are all supported in the implementation of the activities via an extensive network of support organisations. These organisations are chosen to be able to give the project advice and expert input, when so is needed. Via this wide-spread network, information and knowledge will be shared among stakeholders and
to the public, thru the different platforms that are chosen within the project. Supporting organizations in the Pilot LNG project are visualized with logos in the project organization figure below.

2.1.1 Preem AB

Preem AB is the largest oil company in Sweden, with an annual crude oil refining capacity exceeding 18 million m³. Preem’s two refineries are among the most modern and environmentally friendly in Europe as well as the world. Preem’s activities include production, sales, distribution and trading of feedstock supplies. The company produce and sell gasoline, diesel and heating oils to other oil companies, industrial customers and private individuals in Sweden. About half of the production volumes are for export markets. Preem’s portfolio of products also include industrial lubricants.

As such, Preem is large customer of the oil/chemical tanker segment in the region in question. The Skangas LNG terminal is located at Preems facility in Brofjorden. With this unique roll that Preem occupies in this particular market, it is a partner company for JIP SCANBUNK, FLEXI and EVO belonging to activities 1, 2 and 4.

2.1.2 Skangas Terminal AB

Gasum (holding 51% of Skangas) is a Finnish expert in natural energy gases. The company imports natural gas to Finland and upgrades natural energy gas. The company transmits and supplies them for energy production, industry, homes, and land and maritime transport. Lyse (holding 49% of Skangas) is a Norwegian Group, operating within the fields of electricity generation, distribution and telecommunication. The LNG terminal in Brofjorden is owned and operated by Skangas.

As such, Skangas is the principal partner and activity leader in activity 1 which revolves around constructing a connection between the LNG terminal and loading/unloading dock as the jetty. Skangas is also a partner in JIP FLEXI belonging to activity 2, as it will act both as a customer of feeder capacity and a supplier of LNG as bunker in that venture.

2.1.3 Rederi AB Donsötank

Rederi AB Donsötank is a family company registered in 1953, and since then the business has grown and more vessels has been acquired. The company owns and operates five tankers and has around 150 employees at sea, and 13 at the office. Donsötank has a long tradition of shipping from the beginning of the 19th century when the bunker operations started in Gothenburg. The experience through generations has made us an innovative and reliable partner in shipping.

Rederi AB Donsötank is the principal partner and activity leader in activity 3, Short sea distribution and bunkering (SSD&B). SSD&B is concerned with building a new and innovative tank design in a LNG bunkering/distribution vessel.

2.1.4 Sirius Rederi AB

Sirius Rederi AB (Sirius Shipping) is a family owned shipping company specializing in oil and chemical tanker market but also with a vast knowledge of the bunker shipping segment. The company was founded in 1994 on the Island of Donsö. Sirius operates 11
tankers and a LNG bunker vessel. Sirius Shipping is a shipping company built by people who know traditional shipping, however, it is also a modern and forward looking company. The management is in-house and there is a close integration between the vessels and the organisation ashore.

Sirius is the principal partner and activity leader in activities 2 and 4. In activity 2 the Flexi bunker/feeder LNG vessel is built and activity 4 was the main objective to build a LNG powered oil and chemical tanker, EVOlution.

2.1.5  Erik Thun AB

Erik Thun AB is a shipping company founded in 1938 in Lidköping, Sweden. The core business has always been shipping with special focus on inland waterway and coastal shipping. The company owns and operates dry cargo vessels and tankers. Freighting, manning and technical services for the vessels are administrated in the Group’s own organisation which is certified by BVQI in accordance with ISO 9001:2008. The Group operates 13 product tankers, 12 conventional dry cargo ships, seven self-unloading ships and eight cement carriers.

Erik Thun AB is the principal partner and activity leader for activity 5, LNG sea river (LSR). In this activity an LNG fuelled sea going dry cargo vessel suitable for inland waterways is being constructed.

2.1.6  Scheepswerf Ferus Smit

Scheepwerf Ferus Smit is a Dutch ship yard that has been active in northern Netherlands shipbuilding cluster since 1910. It is an independent family-owned company for new building of commercial cargo vessels of various types. With its two production sites in Westerbroek/Groningen, Netherlands and in Leer, Germany it is one of the largest shipbuilders in northern Europe. Complete design and engineering of the ships are done in-house. Sub-contracting to low cost countries do occur with regards to some components, however, the company is proof that complete construction of ships can still be performed competitively in this region.

Ferus Emit and Erik Thun AB have a three decades long standing relationship where during that time, Thun has ordered all its new builds at this yard. In that respect, FS was foregone choice as a partner in activity 5 which is led by and Thun and has the new building of a new Thun dry cargo vessel as its main objective.

2.1.7  Lloyds Register EMEA

Lloyd’s Register Group Limited (LR) is a global independent risk management and safety assurance organisation that works to enhance safety and to approve assets and systems at sea, on land and in the air. LR, its subsidiaries and affiliates provide services designed to help clients around the world to achieve their business goals, while optimizing safety and quality, and protecting the environment and even to improve environmental performance. Within LR the Marine Business participates in technical meetings of International Association of Classification Societies (IACS), contributes to the development of codes for bodies such as the IMO and helps with the review of ISO standards. LR also acts as a “notified body” for many European Community directives, helping to ensure the proper implementation of essential product safety rules. To support these activities, LR maintains
marine related research activities, carrying out research and development activities and initiates new standards for quality and safety as the boundaries of knowledge and application expand.

LR is a partner in JIP LSR belonging to activity 5, most notably fulfilling the role of classification society in this Activity.

2.1.8 Furetank Rederi AB

Furetank Rederi AB is a third generation family owned shipping company from the archipelago of the Swedish west coast and with its headquarters on Donsö Island. Furetank's own fleet consists of 6 chemical/product tankers. With its subsidiaries, Furetank owns and/or operated in excess of 20 vessels. Furetank is a full scale shipping company which can provide all services needed to meet the demands from existing and future customers. Among the services provided are technical, crewing, safety, vetting and chartering departments.

Furetank is the principal partner and activity leader for activity 6, LNG Conv, which has the main objective to convert a conventional vessel to LNG propulsion. The vessel in question is Fure West which was already at its conception designed and prepared for a future option to be converted to a dual fuel powered vessel.

2.1.9 BUREAU VERITAS – Registre International de Classification de Navires et D’Aeronefs

Created in 1828, Bureau Veritas (BV) is a global leader in Testing, Inspection and Certification (TIC), delivering high quality services to help clients meet the growing challenges of quality, safety, environmental protection and social responsibility. As a trusted partner, Bureau Veritas offers innovative solutions that go beyond simple compliance with regulations and standards, reducing risk, improving performance and promoting sustainable development. Bureau Veritas is recognized and accredited by major national and international organizations.

BV is a partner in Activity 6, LNG Conv. Most notably they fulfil the role of the classification society in this Activity. Classification refers to a range of services performed on a vessel, from its design and construction to its “in-service” status, with the objective to make it operate according to a high level of internationally recognised safety standards. As a classification body, BV is committed to the development and implementation of maritime technical standards to protect life, property and the environment.

2.1.10 Öresund Drydocks AB

Öresund Dry Docks AB (ODD) is one of the leading shipyards in Scandinavia. The shipyard is strategically located in the Sound which provides an advantage with regards to distance to the yard for shipping companies operating the Baltic Sea, North Sea, Bothnian Sea and English Channel. The large production facilities, technical capabilities and staff resources makes the yard a competitive, comprehensive partner for ship repairs, maintenance and rebuilding. The yard also offers the construction of large steel structures through its subsidiary Oresund Steel Construction.
ODD was a partner in activity 6 as it originally was pegged as the yard to execute the conversion of Fure West. However, developments during the project led to this sub-activity to be performed at F.A. Yard instead.

### 2.1.11 SSPA Sweden AB

SSPA Sweden AB is a consultancy company, research institute and testing facility within the maritime industry. SSPA offers testing and optimization services through its ship design department and testing facility which includes a towing tank, cavitation laboratories and maritime dynamics laboratory (MDL). SSPA also offers naval architecture services, simulation services and maritime operation consultancy. About 20% of SSPA business is to conduct independent scientific research in the areas of hydrodynamics, route optimization, maritime safety, risk assessment and maritime logistics.

SSPA also has extensive and decades long experience of managing large, multinational projects. As the coordinator, SSPA has a role in every activity not the least through its role in staffing the JIP leader positions in the activities 1-6.

### 2.1.12 Fartygskonstruktioner AB

FKAB, short for Fartygskonstruktioner AB is Swedish maritime design company, founded in 1961. FKAB is part of the privately held Mattson Group and is still providing ship owners, shipyards and energy companies design service. The company has offices in Uddevalla and Gothenburg. Though its subsidiaries with offices in Shanghai, China, it can also provide support for new buildings in the Far East. FKAB has more than 50 years of experience in designing and developing innovative ship designs in the tanker, passenger ferry, general cargo, dredging vessels and container ships segments worldwide. FKAB is a partner in JIP EVO and LNG CONV belonging to activities 4 and 6. It has most notably contributed in the design of EVOlution and design of the conversion of Fure West.

### 2.1.13 Sveriges Rederiservice AB

Sveriges Rederiservice AB is the registered legal name of the Swedish Shipowners’ Association (SSA). SSA is a branch organisation representing Swedish ship owners with both local and global operations. Swedish shipping aims to achieve high quality both with regards to human health and safety as well as efficient and effective utilization of physical resources.

The Associations main objective is to contribute to creating the best terms of competition for its members. In order to attract more goods to Swedish keel, the Association’s Environment and Sustainability Arena proactively seeks to fins cooperation and close agreements that benefit both the environment and its members. As such SSA is partner in all JIPs and activities.

### 2.2 ZVT – Collaboration

ZVT offers a method and collaboration platform for actors within the maritime sector (e.g. shipowners, ports, cargo owners, component manufacturers, classification societies, Authorities and Agencies). ZVT is used to exchange experiences and find common, efficient solutions to issues concerning safety, the environment, climate and energy efficiency.
Users of the platform like to find common solutions to issues concerning the above mentioned areas and to do so they create Joint Industry Projects (JIPs) where they proceed together. These issues may include e.g. address refining and improving current industry standards as well as finding solutions to new challenges the industry is facing. This means that all aspects of the chain of transport are considered: cargo, ports and ships as well as considerations of infrastructure, financing of new and rebuilt safe eco- and energy efficient ships as well as when more R&D is needed.

Figure 2.2 Schematic illustration of ZVT organisation and its process

The platform has a dedicated reference group, ZVTREF, which consists of Authorities, Agencies and industry representatives. The purpose of the ZVTREF is to look jointly into the prerequisites of an issue and find efficient and usable solutions. The decision support is the outcome of the platform’s industry groups (JIPs) together with the knowledge contribution from the ZVTREFs. Decision support for the development of regulations, research and the implementation of innovations is an important component of achieving the objectives.

The ZVT intangibles such as the knowledge, experience and methodology for performing complex, multi-disciplinary, multi-participant projects.

One of the tasks of the Project Leader for the collaboration platform is ensuring the overall co-ordination of the incoming and outgoing information from ZVTREF, ZVT Steering Committee, Pilots and JIPs as well as ensuring that Communication with the ZVT Pool stakeholders and Dissemination to Platform stakeholders and others is conducted.

2.2.1 ZVT Steering Committee

The ZVT steering committee (SC) is the executive agency of the platform. The SC, which consists of representatives from the Swedish Shipowners’ Association (SSA), Association Ports of Sweden (APS), Finnish Maritime Cluster and ZVT nucleus. Decisions regarding the selection and inclusion of additional partners, the code of conduct, administration of the tool, joint communication activities, etc. are made by this body. The SC does not have an operative role in the conducting of specific projects included in the platform. The SC,
its function and constitution is independent of the projects that are included in the ZVT platform, their financing and participating partners.

2.2.2 ZVTREF

ZVTREF is made up of representatives from the following authorities and organizations: Swedish Maritime Administration (SMA), Swedish Transport Administration (STAD), Swedish Transport Agency (STAG), Swedish Energy Agency (SEA), Swedish Environmental Protection Agency (SEPA), Swedish Agency for Marine and Water Management (SAMWaM), the Swedish Counties’ Administrative Board, the Swedish Ship owners’ Association and Association Ports of Sweden (APS). During the years 2012-2014 was SSPA functioning as the moderator of this body. 2015 and forward the ZVT nucleus has taken over that role.

ZVTREF convenes regularly. Through these meetings the ZVTREF is made aware of existing problems, the likely solutions of which fall within the purview of one or several of the members of the body. That is one of the main function of this body, i.e. a collaborative channel through which proper authorities and agencies are made aware of obstacles that cannot be overcome by any individual private or public sector actor involved in the projects.

The following are the identified common denominators, established by the ZVTREF participating organizations, which they would like to use ZVTREF for:

- Knowledge sharing based on real life cases;
- Finding/defining more energy efficient transport systems and showcasing good examples of collaborations working towards a cleaner environment;
- Providing support for knowledge sharing between decision-preparatory/decision-making bodies and the industry;
- Presenting solution proposals and providing decision making support to achieve long-term, sustainable results.

The ZVTREF, its function and constitution is independent of the projects that are included in the ZVT platform, their financing and participating partners.

2.2.3 Joint Industry Project (JIP)

Joint Industry Projects, or JIPs, refer to the individual, specific projects that use the ZVT for their implementation. A JIP is a temporary, collaborative enterprise that is carefully planned to achieve a particular objective, involving several participants with mutual goals, different resources and abilities. A JIP is primarily defined by the task and the participants working to complete that task. Different JIP participant roles and efforts may differ widely, as can the external sources and internal distribution of funding for the project.
A JIP is managed by a JIP leader. In some JIPs activity leaders are employed to be in charge of the operative management of the specific activity to complete the tasks included in the JIP. The JIP leaders are accountable for the JIP’s compliance with its obligations to the ZVT and external co-financiers. This means that the role of JIP leader contains more stake-holder coordination and administrative control, whereas the activity leader is the operative manager of the JIP.

The JIPs, but also JUPs (Joint University Projects) and JAPs (Joint Authority Projects), communicates with ZVTREF four times per year via the coordinator of ZVT in order to bring relevant issues to that body’s attention. It’s a two-way communication where the different projects provide identified problem areas, suggested solutions and progress reports and the ZVTREF provides feedback on that which fall within its purview. The identified issues are of general interest and are categorized in one of five categories: Vessel, Finance, Infrastructure, R&D or Regulations. The specific issues are graded using a three-tier traffic light colour code: Red, Yellow or Green. Red indicates that the problem cannot be solved at the JIP level. Yellow indicates problems that are need of partial support or clarification and Green indicates that the issue is already resolved. The JIP should also supply the ZVTREF with a progress report where the reference group is kept updated on both technical and administrational issues.

The JIPs also share relevant information regarding the progress of their activities with the other actors involved in the ZVT platform authorized to access that information through appropriate channels e.g. written reports, seminars, workshops, conferences, etc. The recipients of the shared information range from other JIPs, followers and supporters, where the primary purpose is knowledge sharing, also to the ZVT steering committee and external co-financiers.

2.2.4 ZVT POOL and Followers

ZVTPOOL is an umbrella term that includes supporters, followers and other relevant actors that are, in one way or another, and to different degrees, connected to any other projects being implemented through the ZVT platform and who are not operatively or otherwise already included in the other components detailed above. The different actors and organizations that are included in ZVTPOOL have varying degrees of claims and obligations to the platform and its activities.

2.2.5 Project management and coordination

The project management, for this Pilot, refers to the pilot coordinator who was in charge of coordinating the implementation of Pilot LNG with the funding agency and the management of the ZVT, i.e. the coordinator of the ZVT. This provided a single point of contact between the different JIPs involved in the Pilot, partners and activities as well as the funding agency and the ZVT management when it came to the progress of the Pilot. For the daily management and coordination of the Pilot Action, a management team was formed. The Management team is responsible for monitoring the implementation of the project activities. The management team comprised representatives from the partners, the JIP leaders as well as the project coordinator.
2.2.6 Partners' obligations and claims

All the partners involved in Pilot LNG, through their participation in a ZVT project and accepting co-financing from TEN-T, had accepted a number of obligations and are entitled to a number of claims. Failure to comply could in the extreme have result in loss of eligibility for receiving funds from TEN-T and/or ejection from the ZVT cooperation platform and thus the project. The cornerstone of these obligations and claims was knowledge sharing.

By participating in Pilot LNG, regardless of whether the partner was receiving funding or how much they received, partners were obliged to share the knowledge they have acquired/complied/created with the other partners. This is to great extent achieved through the compilation of this report but also by participation in meetings, conferences, seminars, work meetings an alike. The prerequisite for receiving funding from TEN-T was to fully comply with the knowledge sharing ambitions of the project. This was one of the main reasons for TEN-T’s co-financing of the investments of private companies i.e. the fact that the knowledge created while carrying out the projects would become available to parties other than those involved. Furthermore, one of the primary objectives of the ZVT platform is to facilitate information and data sharing that aims to enable the entire industry to cope with common, foreseeable future challenges.

However, in many cases, participating entities are each other’s competitors or customers/suppliers in their regular business activities. Therefore, commercially critical information is, and has been, treated with care. The ZVT-platform, partly via the function of the JIP leaders, is designed to enable and facilitate data, information and knowledge to be shared across different organizational boundaries without compromising the integrity of the classified business information of the different involved parties.

In addition to, and in the interest of, knowledge and information sharing, the partners were required to provide sufficient documentation of the processes and work that was performed within the confines of this project. Some of this documentation will remain internal and enable auditing and evaluation of the project. Other segments will be made available to the other participants as a major vehicle for knowledge and information sharing. Yet other parts will be used for reporting to the funding agency and/or public consumption. Even though the partners have a say in what is used and published in which forum, the requirements for reporting to the funding agency, as specified in the Commission Decision, are mandatory and non-negotiable.

2.3 Roles and responsibilities

The role of the activity leaders were:

- To assemble an activity team
- To be responsible for the implementation of their specific activity
- To be responsible for reporting the technical achievements for each activity to the management team, and for reporting the financial results (together with each partner representative on a quarterly basis)
- To be responsible for procurements needed within the activity and budget monitoring and follow up.
For activity 1 to 6 there were also a JIP-leader to support the activity leader with administrative items. The activity team implemented the activity together and enhanced the team during the implementation as need for such reinforcements arose.

2.3.1 Pilot LNG Steering Committee

<table>
<thead>
<tr>
<th>Pilot LNG Steering committee</th>
<th>Partner representatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSPA Sweden AB</td>
<td>Björn Allenström</td>
</tr>
<tr>
<td>Swedish Transport Administration (Member State)</td>
<td>Emil Fastén</td>
</tr>
<tr>
<td>Mission de coordination GNL (Member State)</td>
<td>Jean-Bernard Erhardt</td>
</tr>
<tr>
<td>Preem AB</td>
<td>Patrik Johansson</td>
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<tr>
<td>Skangass Terminal AB</td>
<td>Peter Blomberg</td>
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<tr>
<td>Rederi AB Donsötank</td>
<td>Roger Nilsson</td>
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<tr>
<td>Sirius Rederi AB</td>
<td>Jonas Backman</td>
</tr>
<tr>
<td>Erik Thun AB</td>
<td>Henrik Källsson</td>
</tr>
<tr>
<td>Scheepswerf Ferus Smit</td>
<td>- Not participating</td>
</tr>
<tr>
<td>Lloyds Register EMEA</td>
<td>Anders Höfnell</td>
</tr>
<tr>
<td>Furetank Rederi AB</td>
<td>Clas Gustafsson</td>
</tr>
<tr>
<td>BUREAU VERITAS</td>
<td>Antoine Breuillard</td>
</tr>
<tr>
<td>Öresund Drydocks AB</td>
<td>- Not participating</td>
</tr>
<tr>
<td>Fartygskonstruktioner AB</td>
<td>Claes Claesson</td>
</tr>
<tr>
<td>Svensk Rederiservice AB</td>
<td>Carl Carlsson</td>
</tr>
</tbody>
</table>

Table 2-1 Pilot LNG Steering Committee members.

The highest executive body of the Pilot LNG organisation is its Steering Committee (SC). This is regulated in the partner agreement and decision text. The SC is the equivalent of a board of directors in a company. The current members of the SC are presented in Table 2-1. The SC is comprised of representatives from the project partners.

2.3.2 Project Coordinator

The project coordinator was the focal point of the communication between the Pilot LNG projects, i.e. all JIPs and activities, and the external co-financer, i.e. INEA (Innovation and Network Executive Agency\(^2\)). This role entailed collecting and compiling mandatory reports e.g. progress reports, financial reports, etc. and making them available to INEA in a timely fashion. The project coordinator thus had the authority to require the respective JIP

\(^2\) Previously TEN-T Executive agency
and Activity leaders to submit required documentation according to specified templates and timetables.

Furthermore, in the events when any of the JIPs or activities need additional information or clarification from INEA, this contact was made through the Project coordinator. In instances where the project as a whole required communication with other entities, e.g. external parties etc., the Project Coordinator was the position that was authorized to speak on behalf of the project. JIP and Activity leaders were obliged to assist the Project Coordinator in the performance of its duties. The Project coordinator did not occupy an operative management role in the project, in so far as the work to be organized and performed in each JIP and activity fell within the purview of activity, and to a lesser extent, JIP leaders. The Project Coordinator was also tasked to support the activity and JIP leaders in complying with their obligations according to the decision text and its requirements. The role of the Project Coordinator in the Pilot LNG is equivalent to that of the JIP leaders in the individual JIPs.

2.3.3 Activity Leader

The activity leader was the operative project manager of the JIP. This means that the activity leader planned and managed the resources and activities necessary for the completion of the project according to the stated deliverable results and time schedule in the decision text.

The additional obligation that the receiving of external EU-funding and participation in ZVT entailed; there existed a need to separate the role of the operative project manager, i.e. activity leader, and a position responsible for the project’s compliance with these additional obligations. Furthermore, in most JIPs, the involvement of multiple partners notwithstanding, one partner was clearly the main party with regards to invested resources, capabilities and immediate utility of delivered results. The activity leader role was therefore shouldered by a person in that company’s organization.

2.3.4 JIP Leader

The JIP leader was to the JIP as the Project Coordinator was to the entire Pilot project. This meant that the JIP leaders’ responsibility was to primarily support and facilitate the projects compliance with its obligations to the co-funding agency and the ZVT platform. The obligations to the co-funding agency, as detailed in the decision text, could be divided into two categories: conducting the tasks of the project and delivering the promised results as well as formal documentation, reporting and knowledge sharing. The former category is of an operative character and falls within the purview of the activity leader. The second category is what the JIP leader was responsible for.

The JIP leader’s role within the JIP was to support the activity leaders to enable them to produce the necessary work and results for fulfilling the projects obligations to TEN-T and ZVT. Externally, the JIP leader was responsible for liaising with the other JIPs and the Project Coordinator in order to accomplish their task, i.e. documentation of the work performed in the project and its results, reporting of results and financial statements according to the requirements of the co-funding agency and facilitating knowledge sharing with other entities, e.g. partners, followers, the public, etc.
2.4 Coordination, communication and documentation

The activity leader, in relation to project organization and management, enjoyed a considerable amount of autonomy in how they managed their responsibilities. Depending on the specific tasks, the delivery timetable and JIP budget, they were free to plan, allocate, control and manage the work load and resources as they saw fit. The coordination with other JIPs and compliance with the formal obligations of the JIP to TEN-T and ZVT was the responsibility of the JIP leader.

In order to be able to accommodate follow up and reporting, knowledge creation and knowledge sharing, the progress of the project work was documented continuously and in detail. It was the responsibility of the JIP leader to make sure that each JIP continuously documents its activities, progress and insights gained from the project. One of the main qualifiers for TEN-T co-financing and motivations for utilizing the ZVT platform was information sharing.

A ZVT Communication and Dissemination tool was available for the Pilot and its comprising JIPs and it included three channels:

- Websites (and supporting tools)
- Seminars and conferences
- News Flows and mailing lists

2.4.1 ZVTREF meeting

The ZVTREF convene once every three months as part of the ZVT operations. It was to these meetings that the JIPs reported their progress via a standardized protocol as described above.

The coordinator of ZVT collects and coordinates the JIP G/Y/R reports and progress reports as well as the progress reports from the other active Pilots and projects, and compiles a List of Actions for the Agencies and Authorities. At these meetings the coordinator represented the Pilots and JIPs and ensured that meeting minutes were written and relevant documentation was compiled. ZVTREF communicated their progress and requests to the JIPs via meeting records and documentation e.g. meeting minutes or other documentation.

2.4.2 ZVT Steering Committee meeting

The ZVT Steering Committee meet at least once a month. When necessary, the Pilot Coordinators were also called to attend these meetings during the duration of the Action. Fixed items on the agenda were organizational issues, financial issues and communication/dissemination issues for the platform users as well as the platform in itself. It is also here that Code of Conduct issues are raised and decided upon. The ZVT Steering Committee communicated with the Pilots and JIPs via meeting minutes and documentation.

2.4.3 Internal JIP meeting within the Pilot LNG

The JIP leader maintained regular contact with the activity leader in order to remain updated about the progress of the JIP and to make sure that the obligations for which the
JIP leader is responsible were met. The JIP leader called internal JIP meetings when the need for such arose. However, at a minimum, all JIPs assembled for a meeting before and after each ZVTREF meeting. This was in order to document the progress of the JIP according to the standardized G/Y/R report as well as progress report to ZVTREF, and to enable the JIP leaders to communicate pertinent information about the progress of work in the other entities to the individual JIPs.

2.4.4 General assemblies

Several times per year, all the partners were called to a general assembly. These meetings were documented by a written record e.g. minutes and action agendas. The purpose of these meeting were to create an opportunity for the partners to discuss issues of general interest for the project as a whole, share information, coordinate efforts or make decisions that was outside of the purview of the Project Coordinator.

Typically, representatives from the co-funding agency, TEN-T EA at first and INEA at the later stages, were invited to. Normally, all activates presented their progress and plan going forwards. This was also where the Project Coordinator could raise issues that concerned everyone face-to-face without having to go through intermediaries or meet with each partner individually.

2.4.5 Documentation of results

To enable reporting, knowledge creation and sharing the actions taken and the progress of the project were documented continuously and in detail. The JIP leaders were tasked to make sure that proper documentation routines were in place for the JIP. This documentation contains the necessary information for creating the mandatory reports and results presentations in addition to follow ups and evaluations detailed in activity 7.

In short, the data and information recorded through continuous documentation have allowed for evaluation of the results in individual JIPs from technical, operational, environmental and financial points of view. The compilation of results mentioned in activity 7 is based on detailing exactly what measures were taken for fulfilling the objectives of the respective JIPs, in what order and why and also the expected results of the actions and the actual outcome. Even insights gained and conclusions drawn from the process have been included in this material.

2.4.6 Dissemination

Dissemination of results are achieved through conferences, meetings and workshops, official reporting to ZVT and TEN-T and reports intended for followers and the general public. The content of the dissemination will vary dependent on the specific channel. Any material intended for publication needs to be approved at the appropriate level. Presentations at meetings, workshops and conferences require approval from the JIPs. Official reports to TEN-T and public reports are to be reviewed and approved in advance by the steering committee.

Below a list of dissemination activities carried out in the project is given:

Dissemination 2013:

- 4 times per year ZVTREF meets including Authorities, Agencies and industry representatives from Port and Shipowners’ Associations
- Collaboration between the JIPs regarding structure with EU, 4 times during 2013
- Kick-off for Pilot LNG was arranged in December 2013

External presentations have been arranged:
- During Sweden Maritime Day, April 2013, the JIPs within Pilot LNG presented themselves as a collaboration group
- During the Baltic Ports Conference, September 2013, the Pilot LNG aims were presented
- At the Ten-T Days in Helsinki/Tallin, October 2013, the Pilot LNG was presented
- At the yearly Swedish Gas Days, October 2013, the Pilot LNG was presented
- At HELCOM Maritime, November 2013, the Pilot LNG was presented

**Dissemination 2014:**
- Quarterly reporting to ZVTREF comprising Authorities, Agencies and industry representatives from Port and Shipowners’ Associations
- Three PPP meetings in the Baltic & North Sea Area have been arranged at which Pilot LNG has been presented
- The first 6 activities of Pilot LNG equals 6 Joint Industry Projects, all of which got their own website up and running during Q2 2014 as well as and overall Pilot web at the ZVT site
- In Q3 2014 the Action Pilot LNG was included in the Baltic Sea Roadmap as the example for alternative fuels infrastructure in the area
- Several articles have been published in among others; LNG Industry Magazine, Swedish Dagens Industri and Shipping Gazette
- In October 2014 the LNG Terminal of Action SCANBUNK was inaugurated
- In November 2014 mini-videos were made for each Industry project, in total 5 movies presenting the Pilot LNG action status

External presentations have been arranged:
- In January 2014, Pilot LNG was presented at the Sustainable Baltic Sea Shipping Seminar onboard Viking Grace
- In March 2014 projects from the action Pilot LNG was presented at the ESSF subgroup LNG meeting
- In June 2014, Pilot LNG was presented as one of the actions in the Baltic area at the 16th Baltic Development Forum Summit
- In June 2014, Pilot LNG was presented as one of the actions in the Balitc area at the 5th annual forum of the EUSBSR
- In September 2014, Pilot LNG was presented at the Baltic Ports Organisation Conference in Bornholm
- At the yearly Swedish Gas Days, October 2014, the Pilot LNG was presented
- In October 2014, Pilot LNG was presented at the IVL Baltic Sea Conference
- In October 2014, Pilot LNG was presented at the Oceans and Society seminar
In November 2014 Pilot LNG, with its different industry project groups, presented the progress of establishing an LNG infrastructure during a 3 hour session at the Motorways of the Sea Conference

Dissemination 2015:
- MoS conference No. 2 25-26 March in Venice
- Maritime Stakeholder Platform in the Baltic Sea Region - EC Maritime Affairs, 26-27 March
- ZVT Organisation development, White Paper and Financial Instrument, 28 April
- MoS conference No. 3 20 May in Liverpool
- Åland Maritime Day - presentation regarding Baltic Shipping Policy ws, 21 May in Mariehamn
- Sweden and Finand Harbour CEO conference, 27-28 May
- 11th Integer Emissions Summit Europe 2015, 16-18th June in Brussels
- ESSF LNG Sub-Group in September in Brussels
- MoS conference No. 4 in Gothenburg , 9-10 November
- Danish Society of Naval Architecture's LNG Seminar , 16 November Copenhagen

Online material in regards to Pilot LNG:
Pilot LNG site; www.zerovisiontool.com/PilotLNG
Industry Group (activity) sites; www.zerovisiontool.com/ScanBunk
www.zerovisiontool.com/Flexi
www.zerovisiontool.com/SSDB
www.zerovisiontool.com/Evo
www.zerovisiontool.com/LSR
www.zerovisiontool.com/LNGconv

Video; 2014 www.zerovisiontool.com/gotmos/videos

Presentations;
2014 www.zerovisiontool.com/gotmos/presentations

Progress and news; www.zerovisiontool.com/timeline/
www.zerovisiontool.com/news

All the JIPs and their corresponding activities included in this action are presented in detail in this section. This includes a description of the implementation of the activities including deviation reports and explanation for terminated activities.
3. Implementation of activities

The Action Pilot LNG has been divided into eight activities where two activities (7 and 8) concern compilation and evaluation of results and project management and dissemination. The other six activities are described below. The purpose of the presentation below is to describe the content and implementation of the respective activity. To some extent the progress of the activities are also disclosed.

Two of the six activities, activities 3 and 4, have been partly or totally aborted underway and are not planned to be completed in the foreseeable future. Activity 2 is significantly delayed which means that though the vessel is being built, it is not going to be delivered sooner than the fourth quarter of 2016 i.e. one year after the completion of the TEN-T co-financed portion of the project.

3.1 Activity 1 – SCANBUNK: LNG terminal to jetty connection

The objective of the activity has been to develop a hub for LNG bunkering in Scandinavia. The capacity of the constructed storage tank is 30 000 m³ and the present operation permit allows a total handling of 250 000 tonnes of LNG per year (see Figure 3.1).

Approximately 20% of the capacity is used for bunkering purposes and only this part has been co-financed. The connection from the LNG Terminal to a Jetty in Port of Brofjorden will allow bunkering vessels and LNG fuelled vessels to fill LNG directly from the existing terminal in the scenarios where it is more efficient to bring the ship to the quay or to bring the bunker vessel to the ship.

The Activity includes the design, certification, contracting/building, commissioning and start of operation of the ship bunkering system. Concretely the Activity is divided into the following sub-activities:

- Installation of 800 meters filling line connection, from the LNG terminal in the port of Brofjorden to the jetty, including foundations, pipe-bridges and a culvert for passing a transport road. The jetty has been extended to accommodate
bunkering vessels for loading directly by the vessels, operating on LNG as fuel, at the jetty.

- Installation of a LNG tank pump including engineering, foundations at the tank roof, electrical installation and facilities for control of the ship bunkering system.
- Jetty connection to the pipeline including loading arms, valves and facilities for the loading arms.

### 3.1.1 Progress of the Activity

The Activity Milestones were three in total where Milestone 1 included a finalised design for the LNG terminal including the LNG tank, foundations, piping for import, control system, electricity and bunker terminal arrangement. Milestone 2 regarded a permit to be in place for Activity 1.

Milestone 1 and 2 were fulfilled in 2012 and The ‘Grand Opening’ of the terminal took place in the fall of 2014.

During 2014 pre-commissioning, commissioning and testing were the major activities, according to plan. Quality testing of equipment and improving interfaces between different steering and control systems were vital for a successful implementation. In addition, there were adjustments made on some of the crucial equipment.

In 2015 installation of pipes, valves, pump, instrumentation and control systems interfaced with existing operational system/DCS was performed.

Milestone 3 includes a fully operational bunker terminal for Activity 1. The final installation of the pump for the bunkering of vessels will take place during 2016. All pipes and instrumentation is in place as planned. As a new EN standard for Fiscal Metering has entered into force (MID) during this project Skangas will re-calibrate and perform some transmitter change to the already in place Coriolis flow meter, at the jetty (additional cost reported). This will secure correct flow and quantity when exporting LNG to carriers/ receiving vessels (IGC/ IGF).

Tie-in’s for future connection to all of Preem’s jetties will be implemented when the LNG pump is installed, to serve all LNG fuelled vessels loading/ discharging at Preem’s refinery.

Design of pump has been changed from 1000 m3/h at 5 bar to 1000m3/ h at 1 bar down at jetty, due to purpose fitted. Delivery of pump is postponed to mid-2016 and thereby some left-overs related to pipe-/ valve installation on tank top (tie-in) and commissioning activities will require attention in late 2016.

All in place fitted to serve the Flexitank Coralius. Subsequently, Skangas sees that it would be wise to install some more flexible systems to serve all kind of vessels allowed mooring at jetty 5 in Brofjorden - Preems refinery.

### 3.1.2 Deviations from the planned activities

Everything is according to plan, with the exception of postponed delivery of the LNG pump and a major increase in costs overall.
3.2 Activity 2 – FLEXI: Bunker/feeder vessel

The objective of Activity 2 is to develop the LNG bunkering infrastructure in the Skagerrak/Kattegat area by introducing a fast, efficient and safe bunkering system together with procedures for LNG bunkering both inshore and offshore. For this, an innovative bunkering and feeder vessel is designed and under construction. In cooperation with the Brofjorden Terminal (Activity 1), the vessel will offer ship-to-ship LNG bunkering service to any commercial ship-owner and operator. In this sense, the vessel plays an essential part of the infrastructure chain necessary to provide LNG to vessels operating in the Baltic Sea and thereby also critical in order to establish LNG as a commercially competitive fuel. The vessel original specifications are; 99 m of length, 19 m of breadth, 5.4 m of draught, 13.5knot of speed at 85% MCR (Maximum Continuous Rating) plus 15% sea margin with ice class 1A. Cargo tank capacity will be 5700 m3 of LNG at 100% full tanks with a loading-/discharging rate at 1000 m3/h. An artist’s rendering of the vessel is shown Figure 3.2.

3.2.1 Progress of the Activity

During the first year of the project, initial design of the vessel was conducted in parallel with discussions with potential clients regarding service speed, cargo capacity and operational profile. Meetings and discussions with component manufacturers of major components and discussions with national and non-governmental regulatory bodies and organizations were also held.

Figure 3.2 Artist rendering of the first Sirius LNG Bunker Tanker (Flexi) – M/T Celsius

The preliminary design of the vessel was completed in December 2013 and reported in an outline specification describing; the main particulars of the vessel (i.e. size, cargo capacity, speed, etc.), a makers list of the major components (engine, generators, LNG tanks, etc.) and a preliminary General Arrangement illustrating the vessel layout. At the same time a Letter of Intent was signed together with Preem and Skangas regarding a long time charter of the vessel.

Due to high standard demand on technical performance the vessel was chosen to be constructed in Europe. Nine European yards were identified and approached for offers. Evaluation of the offers was ongoing during the end of 2013 from which a short-list with three yards resulted.
The largest portion of design related work is in the detailed design, which is usually done by the yard in the beginning of the construction phase. The first part of the detailed design includes the main Classification drawings, such as the mid-ship section, plate expansion drawings and fore- and aft-body drawings. When these are approved, construction drawings for the actual building of the vessel are produced. These include drawings of every plate that needs to be cut and welded, pipes that need to be bent and machinery and electric outfitting drawings. Construction of the vessel was planned to start in the beginning of 2014, but due to the delay in the project, much of planned design work never was carried out on time (see 3.2.2)

Most of the planned certification related activities were initiated once a contract with a yard is signed and building of the vessel was commenced in late 2014/early 2015. The Classification Society has a central role in this process as they monitor the entire construction of the vessel, ranging from reviewing and controlling drawings to inspecting installations and outfittings. In September 2014 the Approval in Principle from the classification society, Bureau Veritas, corresponding to Activity Milestone 4, was officially issued.

Steel-cutting is often referred to as the starting point of the manufacturing. That is when the detailed design is completed, steel sheets have been delivered to the yard and started to be cut into different parts and pieces. Closely after the basis of the hull is formed when Keel Laying and building the hull sections. According to the original time plan this should have been done during spring 2014 but instead it commenced in the December 2015.

Commissioning and operating is the final phase of a new building. Similarly to the other sub-activities, no work has been conducted since the construction of the vessel was delayed. The prognosis for the completion of this sub-activity is late 2016/early 2017. Due to that the project has experienced some delays some of activities will be performed after the end of the TEN-T cofounded portion of the project. Certification will be completed with the issuing of all classification and flag state certificates as well as the final certification for the crew. Contracting and Building will be finalized and include completion of sections, main machinery components being delivered, block assembling, launching of the vessel, fitting of the LNG equipment incl. tanks, piping, safety systems, bunkering equipment, arrangement for LNG machinery and safety systems for operating on fuel with low flash point. Commissioning and Operation will also be completed and include outfitting, commissioning, gas trails, sea trails and the delivery of the vessel to the owner.

### 3.2.2 Deviation from planned activities

Activity 2 relates to milestones 4 and 5. Activity Milestone 4 - Approval in Principle from Classification Society, originally due 26/02/2013, was extended to 31/05/2014, and first met in 09/2014. Likewise, Activity Milestone 5 - Vessel delivered, originally due 01/07/2015, was initially extended to 31/12/2015. During mid-2014 it became evident that this dead-line would not be possible to meet and thus moved further forward in time to 31/01/2017.

A lot of time and efforts have been put into the design of the vessel to ensure that the design is optimal for the intended trade that the charterer has in mind. The design have been optimized for fast and reliable bunkering operations as well as short sea feeding. Special consideration has also been taken to the crew onboard and the work environment.
For example, during the design of the deck area, the area has intentionally been kept as clean as possible to make it easy to work out on deck during bunker operations. In the end of 2013 the outline specification for the vessel was completed and the shipyard tendering process was initiated. Due to high standard demand on technical performance and solutions along with importance of meeting delivery dates, it was decided to build the vessel in Europe. Nine European yards were contacted for offers and evaluation of the offers was ongoing during the end of 2013. The tendering process aimed at selecting the most interesting contractors and the plan was to have a signed building contract in March/April 2014.

Since the work with the preliminary design work was still ongoing during the majority of the autumn/ winter of 2013, the first milestone for the activity, approval in principal (Milestone 4 for the Pilot), was postponed. Originally set to be completed 26/02/2013. After continues discussions during 2013, a LOI (letter of intent) was written with T/C operator for a long time-charter of the vessel in early 2014. The LOI clearly stated that the vessel is to be available for end-users of LNG as a maritime fuel and that it will provide LNG bunker service to “any commercial” ship-owner/operator. The LOI also stated that the bunker vessel will by this be available to third-party access (TPA) and that the trading area will be the Skagerrak/Kattegat area.

During spring 2014 the design work continued according to plan and the contract design was being completed. The selection process of a yard was ongoing and the outcome was that 3 European yards were shortlisted for the next step towards finalizing a contract for building the vessel. After thorough negotiations a ship building contract was signed with Bijlsma Shipyard in Holland. Classification society was also settled to Bureau Veritas. In the end of May (31/05/2014) the classification society issued Approval in principal for the vessel and the first milestone for the activity was achieved (Milestone 4 for the Pilot). Negotiations of the final T/C contract with the operator was prolonged due to a change in ownership in the T/C company. During the negotiation period Sirius entered into a joint venture, Sirius Veder Gas, with the Dutch gas shipping company Anthony Veder to further strengthen the project both financially and organizationally. In the beginning of summer 2014 the project encountered some problem with the contracted yard that lead to further delays and that the yard had to be cancelled and negotiations with other shortlisted yards had to be taken up again. A new building contract was signed between the three parties Royal Bodewes Shipyard in Holland, TGE (tank maker and LNG system contractor) and Sirius Veder Gas AB 18/12/2014. The T/C contract was signed early 2015 and the project was moving forward again.

After signing of the building contract and the T/C contract the project have progressed according to the building plan, but due to delays encountered the vessel is approximately 1 year behind original schedule for the action.

Since the building contract was signed, the vessel design has been completed and the engineering work is progressing with the detailed engineering. Strength and fatigue calculations have been completed. The class is involved and work has started related to class approval of system and construction drawings. Equipment, the steel and other material used for the physical building of the vessel is subject to class approval and approvals are issued continuously.

The LNG cargo tanks were ordered in 2015 from TGE Gmbh. Once completed, the tanks will be transported to Gdansk where they will be fitted into the vessel. The steel cutting and the assembling of the hull sections started at Marine Projects Ltd. in November 2015.
and on the 11th of December 2015 the keel-laying was carried out in the presence of Classification Society Bureau Veritas who issued the certificate for keel laying. During the design process Sirius has had a continuous close dialogue and co-operation with the Classification Society Bureau Veritas to establish a good relationship during the building process and ensure that the outcome of the project is a vessel with highest quality.

3.3 Activity 3 – SSD&B: Feeder vessel with innovative tank design

The objective of Activity 3 was to build a LNG feeder vessel, in order to support the distribution of LNG (Figure 3.3). The vessel was to be designed so that it could function both as a feeder as well as a bunker vessel for customers demanding large bunker volumes. Furthermore, in this activity the aim was to build and demonstrate an LNG propelled feeder vessel with a new, innovative, integrated tank design (see Figure 3.4).

![Figure 3.3 An artist's rendering of the SSD&B vessel](image)

They are built into the vessel as cargo tanks and follow the shape of the hull making them highly efficient in terms of storage volume when compared with a similar sized vessel using conventional storage tanks. This allows a relatively small vessel for each location, thus reducing mooring costs and allowing a broader choice of potential locations.

![Figure 3.4 Illustration of the innovative tank design](image)

Practical methods for the construction of the tank system including welding methods and insulation would have to be developed together with the Yard in this activity. The TEN-T
co-funding relates only to the cost of the, certification, commissioning, operation, design and installations of the integrated tank and LNG fuel machinery. This corresponds to about one third of the vessels total investment.

Figure 3.5 Illustration of a comparison of the innovative SSD&B tank design and a conventional LNG tank

The main dimensions of the vessel are 99.8m of length, 18.4m of moulded breadth, 8.9m of moulded depth, 12.5 knot of speed at 90% MCR (Maximum Continuous Rating) and 6200 m³ of LNG cargo tank capacity 100% full cargo tanks. The innovative aspect of this activity, not being tested before, is the new LNG tank design. The tanks are non-pressurized and integrated in the hull giving a better use of the space on-board (Figure 3.5). The aft tank will also be able to deliver LNG to the propulsion system. In the future the same type of tank could be used as a cheaper solution for bunker tanks on new buildings, especially for larger vessels.

3.3.1 Progress of the activity

The first milestone (milestone No. 6), certificates for the LNG tanks and piping installation as well as the LNG system for providing the machinery with fuel, had been fulfilled in November 2013 by a Design Approval from Classification Society. Already in mid-2013 a contract were signed in form of time charter term sheet, however, only for two plus two years. Regarding activity concerning, an approval in principle, based on early design drawing, was issued by Class in 2013.

In the spring of 2014 difficulties were arising since the long term financing from western banks was not possible to achieve due to the requirement for a time charter contract of minimum five years compared to the signed contract of two-plus-two-years. The first shipyard contract was therefore cancelled due to the delay and the decreasing feasibility of securing viable long term financing. A second contract had been negotiated and signed with another shipyard in order to ensure that the project would continue in case the financing/chartering issue would get resolved in a timely manner.

However, the new contract could not be effectuated due to the failure to secure a chartering contract of at least five years, as per the banks requirement, or, to secure financing on other, viable terms. Other potentially feasible approaches were explored in an effort to keep the project alive in the time frame of the TEN-T co-financed portion of the project.
For instance a number of different potential revenue streams, such as working directly with Large Broker Companies and Oil Majors both locally (around the Norwegian coast and Baltic area) and globally as well as end users like and others who need LNG as bunkers were investigated. Even opportunities to potentially leverage the Gothenburg cluster in Sweden for the development of LNG terminals for distribution and bunkering in order to secure the continuation of the project were probed without a timely and feasible resolution.

3.3.2 Deviation from plan activities

The actual building of the ship was planned to start in April 2014, according to a contract with the shipyard Avic Dingheng in China. The progress during 2014 was planned to be about 30 %, and the remaining 40 % was planned to be completed during 2015 including installing of LNG cargo tanks and LNG as propulsion (gas engine and process system). Final design was to be completed in June following the keel-laying at the yard. As the contract has yet to be effectuated the final design has not been completed yet either. Main part of the Certification was to take place at the yard during the installation phase. Regarding contracting and building of the tank and machinery a novel, innovative, integrated LNG tank technology was to be installed, demonstrated and evaluated. The cancellation of this project means that none of these activities have been performed neither. As the construction has yet to begin all sub-activities are basically delayed until such time when the activity resumes.

It can be stated that the Activity 3 cannot be finished within 2015 as was the plan according to the Strategic Action Plan presented in March 2014. Rederi AB Donsötank and the affiliated company Jahre Marine AS are at present looking for a customer for the feeder vessel. If a time charter would had been signed in the spring of 2015, the vessel would have been finished by the end of 2016.

3.3.3 Explanation for terminating the Activity

The lack of success in securing a viable source of financing in the TEN-T time frame has resulted in the suspension of the project meaning that as of the time of this report, the vessel is not going to get built in the foreseeable future as long as the terms of financing and customer demands are unchanged.

Aside from the delays caused by the difficulties of securing commercial financing for the project, an additional explanation for the delay can be the inherent properties of ‘pilot’ project. As described above the tanks on board the vessel is of a new innovative type. They are built into the vessel as cargo tanks and follow the shape of the hull making them highly efficient in terms of storage volume when compared with a similar sized vessel using conventional storage tanks. This allows a relatively small vessel for each location, thus reducing mooring costs and allowing a broader choice of potential locations.

However, the Activity has faced some challenges due to the interpretation of risk in the market for the “new” tank technology. Potential charter companies “unwillingness” to sign a time charter contract due to a certain risk with the new IMO A non-pressurized tank system compared the existing IMO C pressurized tank system has been an issue. This is still an issue even if the IMO A tank containment system as such is fully approved by the class DNV GL through a General Approval of Ship Application (GASA). This in combination with few competitors and a general delay in the development of the LNG infrastructure for small scale distribution and bunkering has made it difficult to penetrate the market.
3.4 Activity 4 – EVOlution: LNG fuelled oil/chemical tanker

The objective of the activity was to do a first new-building with a 2-stroke Dual Fuel Engine. During the process the certification process would have been developed and gaps in existing and suggested rules and regulations would have been identified. The vessel also would have been a customer in the LNG bunkering infrastructure.

The innovative aspect of this activity, not being tested before, is the 2-stroke engine with supporting systems, which is quite different from 4-stroke installations. In particular the LNG supply system will work with high pressure (about 300 bar) as compared to 6-10 bar normal for 4-stroke systems. The energy consumption will be lowered by 10-15% compared to 4-stroke engines and older 2-stroke engine models, at the same time reducing emission levels considerably.

The LNG fuelled tanker vessel for transport of petroleum products and chemicals (see Figure 3.6) was to be built with a dual fuel 2-stroke main engine that will be installed, demonstrated and evaluated. The vessel was also to be implemented with a variety of environmentally efficient solutions that should be demonstrated, both when built and during the journey to get there, leading to new prospects for the development of vessels.

![Image of the EVO chemical/product tanker](image)

**Figure 3.6 Artist's rendering of the EVO chemical/product tanker**

The specifications of the vessel owned by Sirius Rederi AB are 131m of length, 18m of breadth, 10m of depth, 7.4m of draft, 15knot of speed at 90% MCR (Maximum Continuous Rating), 9500m³ cargo tank capacity 100% and 400m³ of LNG fuel tank capacity 100%. This will be the first vessel with a LNG-fuelled 2-stroke engine to be operated in Europe. It will offer manufacturers, Classification Society and owners a first experience of a high pressure LNG fuel system for a tanker.

3.4.1 Progress of the activity

Activity 4 was terminated during 2014 as it became evident that completing the project according to plan and within the time frame of the TEN-T financing was not feasible. Main design was carried out earlier in the project and reported as an Outline Specification describing; the main particulars of the vessel (i.e. size, cargo capacity, speed, etc.), a
makers list of the major components (engine, generators, navigations systems, etc.) and a preliminary General Arrangement illustrating the vessel layout.

Interesting European yards were presented the Outline Specification and negotiations concerning the construction of the vessel were initiated. During the same period, market conditions for short sea liquefied products changed to the EVOlution vessel’s disadvantage. Commercial interest in this type of vessel decreased since it became difficult to motivate financially. In August 2014 it became evident that Activity 4 could no longer continue and be executed. The Commission was informed and the project was soon thereafter terminated.

3.4.2 Explanation for terminating the Activity

In August 2014 it became evident that the Activity 4 could no longer be continued or delayed for later implementation within a reasonable time frame. A lot of time and effort has been invested in the project by the project members, which during mid-2014 was focused on finding a viable financing. The reasons could be summarized as unpredictable changes in market conditions and market demand.

When the application was submitted to the Commission, the prior analysis conducted of the market indicated that the EVOlution vessel size was ideal and the economy of the project was satisfactory and very much feasible. Market development has since then changed the margins for parts involved in the project.

When the Strategic Action Plan was submitted in the beginning of 2014, the intention was still to continue the project as planned, even though some delays were already a given fact and also reported. Nevertheless, the project was still considered fully possible to complete. Since the last reporting was submitted to the Commission, the market conditions have changed. The following statement will try to highlight factors that the project strongly believes have had an effect on the outcome of the project.

Sales margins to the end user is what ultimately affects the market. The factors that affect the margins vary over time and are not static. The refinery margins and off set possibilities for clean liquid cargoes have decreased since last reporting to the Commission and the trend is most definitely falling. In the next stage this affects the earnings for the vessels since the freights go down. This leads up to that the vessel EVOlution will today be too expensive to build in relation to the estimated earnings for the vessel once in operation, making the calculation of the whole project not economically feasible compared to the original estimations conducted for the project.

In addition to the above, although cargoes are being transported, the trend at the moment is moving towards bigger size volume shipments because the market demands it. Size demand is most likely driven by the refinery margins applicable for this particular size of vessel and the intended market segment in correlation to offset sales margins at this moment and estimations of these for the near future.

The market of the short sea shipping of clean liquid products in the Northern Europe for vessels in the size range of the EVOlution vessel, has as an effect of the above stated trend been declining during 2014 and this affects the possibility to engage in long term commitments right now, such as a long term charter contracts.
In June 2014 Sirius experienced the first indications that the project EVOlution was not going according to plan. The commercial discussions was then enhanced to try to find a way forward for the project and Sirius understanding of the situation was that there was very much a positive attitude among all involved parties to find a good solution.

3.5 Activity 5 – LSR: LNG fuelled dry cargo vessel

The objective of the activity was to design and build a small bulk/dry cargo vessel with LNG as fuel without losing cargo carrying capacity (see Figure 3.7). The vessel was also to be a customer of the LNG bunkering infrastructure and thus contribute to the overall objectives of the pilot action. This activity relates to the building of a LNG dry cargo (cement) sea-going vessel, suitable also for sea transports in river and lakes.

![Photo of the LSR vessel at the yard before the launch.](image)

The innovative aspect of this activity is the design of a LNG fuelled dry cargo vessel with limited space, given the fact that the vessel partly operates in areas with locks.

The dimensions of the vessel, owned by Erik Thun AB, are 110 m of length, 15 m of breadth, 9,85 m of depth, 7,1 m of draught, 12knot of speed at 90% MCR, and 7350 tonnes of deadweight

### 3.5.1 Progress of the Activity

The implementation of the Activity can be divided in two main phases; initializing and execution phase.

In the initialization phase, the primary focus to form the activity group. Typically, several initial discussions between ship owner, ship yard and classification society was held. Another important aspect was to initiate the commercial aspects e.g. discussions with potential transport customers and make estimations of costs related to design and construction of the ship. One clear conclusion from this phase was that the EU-grant was necessary to enable a commercially viable solution. Weak interest of environmental performance from transport customer in combination with a substantially more expensive ship were important factors. Another important aspect was vague availability and price of LNG.

In November 2013 the project went in to a more active phase as it was confirmed that EU commission would support the project. Discussions between partners, component
suppliers, and customers were intensified. A start up meeting between the partners was arranged in November in Lidköping. Important tasks were to:

- Get a freight contract for the ship
- Fix ship dimensions
- Produce rough layouts
- Update cost estimates
- Prepare the classification process
- Negotiate the commercial conditions between partners (parts not covered by EU-grant)

Already from day one in this project Thun had an intention to execute this project together with the yard Ferus Smit. Thun and Ferus Smit has long and strong partnership with more than 28 new buildings the last 25 years. Each new build incorporating small but notable improvements which mutually has contributed to put booth yard and owner in a leading position in each of its segments. A strong and open minded relationship is also imperative to develop this type of novelty ship. All factors are not known in advance and the art of “give and take” is necessary for an efficient development process. This phase was formally closed as the contract between Thun and Ferus Smit was announced in February 2014.

At the time of entering the new building contract, and thusly the execution phase, the main cargo transport customer was not yet contracted. This means that in general all parameters, except for length and cargo handling equipment was locked. This enabled ship design and ship yard vendor procurement to proceed since the critical parts in the design work are located in the bow and the aft. The midship section is parallel and could be extruded if necessary. This is also the reason for differences in ship dimensions between Commission Decision, SAP and final ship as explained under deviations part.

In the summer 2014 Thun decided to build the vessel as a dedicated cement carrier and let her enter the fleet of the subsidiary shipping company JT Cement AS. This is a joint venture between Thun and the Norwegian ship owner KGJ Cement AS. JT Cement owns and operates several cement carriers (DWT < 7500 t) trading mainly in northern Europe. This was announced in September 2014. By this, the final corner stone for this project to proceed was in place. All main dimensions were locked, components could be ordered, design could be finalized and production at the yard started.

As a part of the dissemination process JIP LSR and activity 5 has continuously contributed with news to the project webpage, which gives more insight and also shows images from the main steps in the project. The page will stay online and the articles can be accessed by following this link: http://www2.zerovisiontool.com/projects/lsr/news

3.5.2 Deviations from the planned activities

The activity has been done according to the Commission Decision text. However some minor modifications related to vocabulary and in data in the decision text had to be done. Those changes are described and motivated below and they do in all cases refer to Commission Decision Annexes 1-3. All deviations are related to the transport work and the commercial aspect of finding the optimal business case for this type of vessel. This means that the deviations neither affect the objectives, nor the work or the cost related to the pilot.
action. All deviations are subject to commercial aspects of transport work and general ship design which is not a part of the scope for TEN-T grant.

In the first sentence describing the activity 5, there has unfortunately been a selection of the wrong vocabulary. The original text is:
“A LNG Dry Cargo sea-going vessel, suitable also for inland waterways, will be built.”

This should be changed to:
“A LNG Dry Cargo sea-going vessel, suitable also for operations in river and lakes, will be built.”

The reason for changing this is to avoid misunderstandings since the term “inland waterways” usually has a legal meaning referring to the European directive 2006/87/EC regarding technical requirements for inland waterway vessels. Inland waters are also mentioned under sub activity 5.1:
“The vessel is partly operating in inland waters passing through locks of limited size, thus, the design will focus on finding space and weight saving solutions for the LNG installation.”

This text should consequently be changed to:
“The vessel is partly operating in rivers and lakes passing through locks of limited size, thus, the design will focus on finding space and weight saving solutions for the LNG installation.”

The decision text also includes the main dimensions of the vessel:
"The dimensions of the vessel, owned by Erik Thun AB, are 89m of length, 13.4m of breadth, 8.7m of depth, 5.4m of draught, 12knot of speed at 90% MCR, and 4000 tonnes of deadweight.”

Those dimensions were very preliminary. A large part of the initial work in the project has been related to commercial issues where one fundamental part was to market the ship for potential transport customers with the goal to get a long term time charter or contract of afreightment. The basic transport requirements set by the customer is an important input to the design. When building ships with new technology this is even more challenging. Although the EU funding covers a substantial part of the extra cost related to LNG as a fuel, the ship is still more expensive and has to compete with conventional ships on a tough market.

In this particular case the ship-owner Erik Thun had to change the main dimensions in a later stage to adapt to the requirements from the final transport customer. This process is also mentioned in the text describing sub activity 5.1.

The text related to main dimension should be:
"The dimensions of the vessel, owned by Erik Thun AB, are 110 m of length, 15 m of breadth, 9,85 m of depth, 7,1 m of draught, 12knot of speed at 90% MCR, and 7350 tonnes of deadweight.”

The final dimensions are still in line with the objectives, work description (sub activities) and cost break down of activity 5. The ship is designed to operate in among other Lake Mälaren in Sweden and smaller harbours which constraints the size of the vessel.
3.6 Activity 6 – LNG CONV: Conversion of tanker for LNG propulsion

The objective of the activity was to develop a cost efficient system for converting a vessel for LNG operation, with special emphasis on reducing the cost of LNG fuel tanks. Safe and efficient procedures for maintenance, repair etc. of LNG fuelled vessels, both in daily operation and at Shipyards in connection with planned/emergency visits will also be suggested. The work has been done in close cooperation with a Repair Yard and component makers so as to utilize their special knowledge and to ensure a wide spread of the lessons learnt. The vessel will also be a customer in the LNG bunkering infrastructure. The innovative aspect of this activity not tested before is the LNG conversion kit being developed for a large vessel, powered with a 4 stroke engine in cooperation between designer, manufacturer, owner, shipyard and classification society. This can act as a pattern for future conversion kits to be used by followers. The search for more cost efficient tanks may also give ideas for further development.

Figure 3.8 A photo of Fure West with the LNG tanks digitally rendered for illustration

An existing tanker vessel, the Fure West was converted to LNG operation (Figure 3.8). The vessel operates almost exclusively in the Baltic and North Sea, transporting petroleum products. Originally both a dual fuel main engine and one auxiliary engine using LNG as fuel, as well as innovative LNG tanks with reduced isolation as compared to conventional LNG tanks will be installed, demonstrated and evaluated. Regarding the auxiliary engine, see deviations below. There will be special focus on evaluation of the whole system (main and auxiliary engines) and the new LNG tank specification.

The dimensions of the vessel being converted, Fure West, owned by Furetank Rederi AB, are 144 m of overall length, 21.8 m of breadth moulded, 12.5 m of depth moulded, 5,400 kW of main Engine MCR (Maximum Continuous Rating), 14.5 knot of speed at 90% MCR and 19,200 m3 of cargo tank capacity

3.6.1 Progress of the Activity

The manufacturer of the main engines on board FureWest, MAK, have developed an LNG upgrade kit, and tested it at their facilities with satisfying results. Several concepts for LNG tanks have been studied considering number of tanks, size of tanks, placement of tanks and suitable manufacturer for tanks. A decision was made to improve tank insulation with a superinsulation material. By doing this, the evaporation was reduced and no need for running and modify the auxiliary engine to run on LNG to handle this “boil off” gas.
This reduced the complexity of the overall solution. Piping could be arranged on top (safety aspects) of tank only and a submerged pump is installed in the tank to supply the engine with fuel, instead of relying of “boil off” pressurization. A requirement for an additional compressor was discovered during the HAZID and a redesign was performed. The vessel has normal endurance of approximately 30 days between LNG bunkering. Stability issues were raised concerning MARPOL 22/27 for, among others, liquid free surface. It was solved by modification of the wing ballast tanks 3 & 6 and creating a void tank (cofferdam) in between. A safety assessment was carried out and thus, milestone 12 was reached.

The contract design is the basis for the contract and contains a contract specification, contract drawings and specifications of components at a more detailed level for the LNG installations. Drawings for affected systems have been reviewed and in applicable cases modified to fulfil the compliance requirements of the Classification society and received approval.

The main engine has already a type approval by another class society. The class society has surveyed the ship modifications during the retrofit at the shipyard. These were then commissioned after LNG systems on the vessel were installed. During the commissioning dock trials and sea trials were performed. Certificates for the approved systems were compiled and at delivery the final, major certificates were issued to the owner. The classification society has investigated how the conversion affects other certificates and advised were applicable how to achieve compliance. For example education and training of the crew, the safety management system (ISM) and security procedures (ISPS) have been considered.

The engine conversion kit has been completely assembled and tested at MAK test bed in Rostock and disassembled again into a kit and transported to the yard for final installation on board. The same team making the kit has been in charge of final assembly at the yard in order to ensure a smooth installation and acceptable functionality.

The conversion in its entirety has, in addition to the conversion kit installed on the main engine also included the installation of LNG tanks, piping and the upgrade kit for the auxiliary engines and boilers. It has included the installation of the main engine’s cylinder heads and modified camshaft and new burners for the boilers. Feeder pumps for the LNG and safety systems required for low flash-point fuels have also been installed. Procedures for handling LNG components in connection with maintenance, normal dockings and repairs after accident have been developed. Tests of the affected individual systems are performed in connection to the conversion of the vessel at the shipyard. Trials are done in cooperation between the owner, the classification society and the Shipyard. After the conversion was carried out at the yard, the total performance of the vessel was tested in dock and sea trials. Trials were performed in cooperation between the owner, the classification society and the Shipyard.

The order for the tanks was won by Taylor-Wharton International LLC and the tanks have been manufactured in Taylor-Wharton facility in Slovakia. And transported to the ship yard by road and inland waterways. The tanks and the conversion kit have been installed at F.A. Yard. The conversion itself was rather “straight forward” and the installation did not take more than planned number of days.
3.6.2 Deviations from the planned activities

Due to the decision of the design modification of improving tank insulation there is no longer a need for doing any modifications of the auxiliary engine which was a part of the Strategic Action Plan (SAP). Manufacturing start of LNG tanks was delayed and the ship yard was changed from Öresund Dry Docks to F.A. Yard. However, this did not have an impact on the overall time plan and not affect other activities.
In this section the use of LNG as maritime fuel is evaluated with respect to technical and operational performance. The main focus of the evaluation is the implementation of the activities. This also serves as the basis for the best practice in this regard.

4. Technical and operational evaluation of using LNG as fuel

This section is devoted to sub-activity 7.1: “Technical and operational evaluation of using LNG as a fuel”. Even though activity 7 is meant to deal with activities 1-6, this particular sub-activity does not apply to activity 1: building a connection from the LNG terminal to jetty in the port of Brofjorden. The LNG terminal and the connection to jetty are critical components of the LNG supply chain capability that enable the use of LNG as a maritime fuel. Nonetheless, it does not use LNG as a fuel for its operations and nor does it replace any previous installation which would otherwise allow a comparative technical and/or operational evaluation.

Two of the other activities that are applicable here have been terminated at various stages of progress. Though none had progressed far enough to warrant any meaningful technical and/or operational evaluation in line with what is sought here. Furthermore, the three activities that are evaluated below are different enough, both in process as well as the final result, that the evaluations my not be comparable between themselves.

Activity 2, the Flexi bunker/feeder vessel, is a wholly new component in the system which neither replaces an existing vessel nor could it feasibly be build running on conventional fuel. This leads to an evaluation lacking in comparative elements.

Regarding activity 5, LNG fuelled dry cargo vessel, the choice of fuel is a central consideration and ample historical data exists to allow reasonable comparison with a feasible reference vessel running of conventional fuel. However, these results are not fully comparable with the ones regarding activity 6, LNG Conv, where comparative analyses are made between the performance of the same vessel before and after the conversion. All three activities evaluated below have had unique processes in different commercial and operational environments, which has resulted in the emphasis of the evaluation and analyses to differ between the activities. In this respect, what is lost in terms of comparability between the activities is gained with regards to more comprehensive and rich description of diverse points of interest in the different JIPs.

4.1 Activity 2 – FLEXI: Bunker/feeder vessel

Due to late start of this activity, very little information can be presented at the time of presenting this report.

<table>
<thead>
<tr>
<th>Name</th>
<th>M/T Coraleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Overall</td>
<td>99,6 m</td>
</tr>
<tr>
<td>Breath</td>
<td>17,95 m</td>
</tr>
<tr>
<td>Draught</td>
<td>5,8 m</td>
</tr>
</tbody>
</table>
For the contract design, a detailed specification has been produced and signed as an enclosure to the building contract between Sirius Rederi AB and the shipyard Royal Bodewes B.V. which were signed on the 18th of December, 2014. Also, a General Arrangement (GA) is enclosed to the building contract. The GA has in principle been finalized, only a few minor changes will be made later on in the building process.

The main hull drawings for Classification, like the mid-ship section, plate expansion drawings and fore- and aft-body drawings are being produced. The construction drawings for the actual building of the vessel are an ongoing process and have been since beginning of 2015. The work with these drawings is in an intensive stage right now, but do not inflict any delay on the ongoing process of the actual building of the vessel as many of these drawings are system drawings which will affect the building process at a later stage in the process and there is only minor fine-tuning remaining.

As an attachment to the contract and the specification is a ”Makers list”, including by buyer approved suppliers of all components which the shipyard can chose from. The process is that when the shipyard assigns one of these different makers of a component an Approval document is sent to the owner for signing. Below is a list of some of the main makers that are now approved:

- Basic design                  - Groot ship design BV, The Netherlands
- Design of ship systems       - Marine Service Noord BV, The Netherlands
- Model test                   - Marin, The Netherlands
- Cargo tank system            - TGE GmbH, Germany
- Main engines                 - Wärtsilä Oy, Finland
- Propeller                    - Wärtsilä Oy, Finland
- Reduction gearbox            - Wärtsilä Oy, Finland
- Bow azimuth thruster         - ZF Marine, The Netherlands
- Steering gear                - Rolls Royce, Norway
- Electrical systems           - Alewijnse Noord BV, The Netherlands
- Rudder                       - Becker TT, Germany
- External Cathodic Protection - Corrosion, The Netherlands
- Heaters & system solutions   - GESAB, Sweden
The process with remaining makers not approved yet is in a final stage and will not affect the building process. The shipyard Royal Bodewes B.V. have subcontracted the building of the hull structure, assembling of hull sections, mounting of cargo tanks and outfitting of some of the systems to the shipyard Marine Projects Ltd. in Gdansk, Poland. The work in Poland was started in December 2015. In September 2016 the vessel will be towed to Papenburg in Germany where the vessel will be finalized at Royal Bodewes’ facility. The steel cutting and the assembling of the hull sections started at Marine Projects Ltd. in the end of November 2015 and on the 11th of December the same year the keel-laying was carried out in the presence of Classification Society Bureau Veritas who issued the certificate for keel laying.

![Figure 4.1 Steel cutting ongoing for the flexi vessel](image1.png)

![Figure 4.2 ‘Artist impression’ of CORALIUS](image2.png)

### 4.2 Activity 5 – LSR: LNG fuelled dry cargo vessel

The ship is a dedicated cement carrier (dry cargo) and the first of its kind in the world with LNG dual fuel technology. The main facts about the ship are presented in Table 4-2 below:

<table>
<thead>
<tr>
<th>Name</th>
<th>M/V Greenland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Overall</td>
<td>109,65 m</td>
</tr>
<tr>
<td>Breath</td>
<td>14,99 m</td>
</tr>
<tr>
<td>Draught (summer, loaded)</td>
<td>7,1 m</td>
</tr>
<tr>
<td>Dead Weight</td>
<td>7350 mt</td>
</tr>
<tr>
<td>Speed</td>
<td>13 knots</td>
</tr>
<tr>
<td>IMO number</td>
<td>9734264</td>
</tr>
</tbody>
</table>

**Table 4-2 Main facts of LSR: LNG fuelled dry cargo vessel**

Main features of the vessel are:

- Finnish Swedish Ice class 1 A
- Designed to operate in ambient temperature -35°C - + 35°C
- Pneumatic self-unloading system developed by KGJS
• Wärtsilä 6L34DF Dual Fuel Engine, 3 MW
• Cylindrical LNG storage tank with abt. 130 m3 capacity
• Shaft generator, 1,5 MW (enabling running discharging operation on LNG fuel.)
• Water lubricated stern tube
• Ballast water treatment system
• Optimized hull form
• Prepared for shore power supply (while discharging)
• Classification Lloyd’s Register: LR+100A1 Cement Carrier Ice Class 1A FS *IWS+LMC UMS GF

The LNG function consists of the following main elements:

• LNG storage
  o Tank
  o Tank room

• LNG transfer
  o Coldbox (TCS, Tank Connection Space)
  o Piping
  o Valves
  o Heaters

• LNG driven propulsion and electric power generator engine

• Bunker station

• Auxiliary (support) systems:
  o Water-glycol heating system
  o N₂ Inert gas system
  o Safety system
  o Ventilation gas detection
  o Automation and control systems
  o Electrical installation
  o Pneumatic system

The main LNG-components are illustrated in Figure 4.3 and Table 4-3.

<table>
<thead>
<tr>
<th>Bunker station</th>
<th>Gas valve unit “GVU”</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG tank</td>
<td>DF Main Engine</td>
</tr>
<tr>
<td>“Cold Box”</td>
<td>Ventilation Mast</td>
</tr>
<tr>
<td>Gas fuel pipes</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-3 Overview of LNG main component allocation in the General Arrangement
In the following a general description of each LNG related functions and components can be found together with some conclusions and lessons learned. The text is mainly based on interviews and study visits during the project. Reference document produced by ship yard and Lloyds register are also used as an information source. It should be noted that most reference documents are subject to commercial secrecy and not public available.

4.2.1 LNG storage

LNG is stored in an IMO type C tank (cylindrical vacuum insulated, with dished ends), standing in the bow behind the collision bulkhead (Figure 4.4). The tank volume is about 130 m³ enabling operations with bunkering interval of about 10 – 15 days. The tank is designed for holding the gas in liquid form more than 14 days without critical build-up of pressure from boil off gas.

The LNG tank location should be highlighted as an innovative part of this project. Normally LNG tanks are laying horizontally either on deck or close to the engine room. For this type of small dry cargo ship, placement on deck (as for tankers) or close to engine room (as for ferries, RoRo or similar) would occupy valuable cargo area. In theory it might be possible to have the tank behind the deckhouse, but this would give an unfavourable
weight distribution and in practice this is more of a solution for larger vessels (where the tank weight is a relatively less share of the ship light weight). Hence, by constraints the remaining place to but the tank is in the bow. This adds consequences to solve. One part of this is the transfer and connections from tank to engine room which will be very long. Another advantage with this tank arrangement for a cement carrier is that the vessel obtains a lower center of gravity and thereby has improved stability compared to an on-deck solution. This again optimizes the cargo intake.

Conflicting consequence of arranging the tank in the bow is that several of this volume is normally utilized and designed for other purposes and considerations. The shape of the bow is a key factor for good ship energy efficiency and low hull resistance in calm and heavy sea conditions and also for performance in ice navigation. Bow thruster, anchoring and mooring systems, ballast tank is also arranged in the bow area. This arrangement gave implications for the design and necessitated stores and other equipment had to be located elsewhere.

Also the rules and regulations set constraints. The IGF-code stipulates that LNG tanks may not be placed closer than B/5 from the side of the ship at the waterline. Obviously not a too favourable rule for a wedge shaped bow and a cylindrical tank. Through a close cooperation with Lloyd’s Register and a risk based approach by utilizing direct calculations, it was possible to show that the gas tank location in this project had equivalent protective location as the intention of the IGF rule.

The outer shell of the tank could then be extend outside the B/5 limit resulting in improved gas storage capacity which is essential for this design. Necessary ice strengthening of the hull for complying with the Finnish Swedish 1A rule notation, was symbiotic beneficial adding strength to the hull for withstanding collision impact energy. Similar rule also stipulates that the distance to the gas tank from the ship bottom should minimum be 2,0 m. An initiative to look into equivalent process to for this prescriptive standard was initiated. By considering the risk against benefit and the consequential cost it was decided not study this further.

Figure 4.5 Transhipment of LNG tank to IWW barge in Rotterdam

There is no drip tray underneath the tank. Tank is double skinned. In this space there is 100% vacuum. In case of a LNG leak the vacuum will disappear, and a valve is automatically opened to the foremast vent line. In this line gas detection is located.
The transportation of the tank was also challenging. The tank is a large and heavy piece of metal resulting in some shipment challenges. In this case it was transported overseas from the Cryonorm’s factory in India to Rotterdam and from there transhipped via an inland water way by barge directly to the shipyard (Figure 4.5).

4.2.2 LNG transfer

Attached to the LNG tank is the so called cold box (Figure 4.6) containing a LNG vaporizer (using waste heat from the main and auxiliary engines), valves and piping connections. The cold box is a totally gas tight enclosure also including necessary piping, valves and instrumentation. The control of the equipment in the cold box is through a panel located in the forecastle and engine control room. The cold box also has a functionality to vaporize gas to the tank to keep the pressure as the gas is consumed. Master gas valve is located in the compartment in front of the superstructure, where the gas enters the engine room.

Figure 4.6 Schematic illustration of the cold box

From the cold box the gas is transferred in double walled pipes out to the starboard side of main deck where all deck piping and also cabling is concentrated. The gas piping on deck is single walled until it penetrated the bulkhead in front of the deck house. Close to the deck house is also an additional heat exchanger installed since the long pip routing in combination with harsh winter condition might cool down the gas beyond the temperature range for the DF engine (Figure 4.7). At this station is also a safety valve located to enable manual closing of gas supply from the outside of engine room.

Figure 4.7 All piping is centralized on starboard side (2 Grey on top – heating to the TCS and cooling water to the air cooler of the discharge installation, Red – firefighting water, Black – inert gas, Green – compressed air, Yellow – gas and outer side - cable routing)

From the deck house front the piping continues double walled to the GVU (Gas Valve Unit) which is a part of the engine installation (Figure 4.8).
4.2.3 LNG engine

The gas interface to the engine installation is basically the GVU. The main function of the GVU is to regulate the pressure of fuel gas and to ensure a fast and reliable shut down of the gas supply. The gas valve unit is placed inside an air tight housing and the housing is ventilated continuously. Any gas leakage will be detected immediately and the gas supply will be shut down. This is a very important advantage since the enclosed design enables a placement close to the engine as with other auxiliaries. The alternative would require a separate GVU room which would be a fairly complex and expensive installation. The gas valve unit also performs a leak-tightness-check prior to the start of the engine or a switchover from diesel to gas mode. The gas engine is of dual fuel type and the smallest available in the Wärtsilä’s 34 DF engine program (Figure 4.9). The engine is a four stroke, medium speed range type. Pilot fuel injection is done via a common rail system.
Basically, the engine is the same as the standard 32 engine by Wärtsilä, but instead of one fuel system this engine has three, one for pure MDO, one for MDO pilot fuel and one for the gas. The pilot fuel is needed to spark the combustion process and equals normally less than 1% of the total full load energy consumption. The alternative to a DF engine would be a spark plug ignited pure gas engine. In practice this is not an option as it requires redundancy for fuel storage and supply systems and will be prohibitive due to space requirement and cost. The vessel would in case also be less fuel flexible.

Selecting an optimal LNG fuelled engine for a small cargo ship is in many cases difficult. Availability of a dual fuel engine with a suitable power is limited. There is a glitch in Wärtsilä’s program between the 20 DF and 34 DF bore engine in the power range from 1,6 to 3,0 MW. For MDO single fuel engines, this gap is filled by a 26 bore type which is unavailable in a DF version.

For other engine manufacturers, the situation is identical. If the required power is between 1,6 and 3,0 MW, the alternative is either to install two smaller engines or one too powerfull engine. Booth options is costly but the latter is in practice the only viable solution for this ship type technically and economically.

Switching between the fuels goes totally seamless and the only physical thing which can be noted is a small reduction in noise levels due to a more “soft” combustion process when operating on LNG. Figure 4.10 illustrates the fuel indicotor at the bridge. The engine will fully automatic switch to Marine Gas Oil (MGO) if the engine or gas feeding system has a malfunction. In gas mode the engine fulfils the IMO Tier III levels and in MGO-mode it fulfils the Tier II levels. Also emissions from sulphur, CO₂ and particles are substantially decreased in gas mode. This is also discussed in the environmental performance sections.

### 4.2.4 Bunker station

The bunker station is located behind the forecastle on starboard side, on the main deck level (Figure 4.11). The maximum filling rate is 40m³/h and the tank can be filled up to maximum 83% of the total volume. Access to bunker station inside is through three weather tight hatches. A portable spill tray must be fitted below the bunker hose prior to bunkering.

Two control valves are placed in the bunker station, one manual (safety reasons) and one automatic to control the flow of NG. The connection to bunker supply goes through a bolted flange connection and the ship carries several adapters. In the future it is planned to add a quick connection of Mann Tek type. Between the flange connection and the LNG
A breakaway coupling is fitted to avoid leakage in case the bunker hose is loaded for some reason. Both the ship and the bunker supply unit must have an ESD (Emergency Shut Down) system connected f.i. via a safety hose. In case something in the safety and control system triggers an ESD e.g. a pressure loss, it will be activated simultaneously on the receiving and supply side.

Figure 4.11 Bunker station seen from midship and outside of the vessel

After completing the bunkering if LNG, the system is purged through the cryogenic hose by the nitrogen gas released by operating manual valves at the bunker station.

Figure 4.12 First LNG bunkering at the Ship yard 2015-12-18. The orange hose is the ESD connection and the white the cryogenic hose (image courtesy MF Shipping).

The bunker station also includes pressure & temperature transmitters for monitoring reasons. The maiden bunkering of the ship is illustrated in Figure 4.12.
4.2.5 Auxiliary (support) systems

Water-glycol heating system

Hot water is used for vaporizing the LNG as operationally required, to gas form and also for preheating it to a sufficient temperature prior to injection into the engine’s combustion chamber. Waste heat recovery from the main or auxiliary engines cooling water is utilized through independent hot water supply to each unit.

Inerting

The purging system allows the different sections of gas pipes and systems to be inerted (drained from natural gas) with nitrogen gas. Inerting clears fuel and piping systems from natural gas. A nitrogen gas generator on board is used for production of inert. This is a very essential safety element in several procedures f.i. like bunkering and maintenance on the system.

Safety systems

In terms of hardware, most safety systems are built in to the specific components or parts of the LNG-function. The main objective is avoiding methane/natural gas leakage and if it should occur, minimize or omit the consequence. The natural gas in liquid phase has a temperature of about -162°C and would result in a brittle steel structure adding risk for structural failures and personnel hazard if it is “let loose”. Vaporization will be accelerated in contact with water. Methane in gas phase goes quickly up into the atmosphere. However there is always a risk of fire or explosion if a correct mixture between air and gas meets an ignition source.

In the daily operation at sea on LNG, the likelihood of incidents are very small. Most risks are related to bunkering operations and maintenance. In this context standard procedures, checklists and vocational training are as essential as the specific safety systems.

Typical added safety systems are:

- Ventilation and gas detection
- Valves
- ATEX (explosion) protected equipment in all gas hazardous spaces/zones, applies to lights, computers, antennas, fans etc.
- Inert gas system
- Protective location of tank
- Use of proper personal protective Equipment (PPE)
- Management systems mitigating the identified hazards

Ventilation and gas detection

Ventilation and detection plays an important role in the gas systems. All spaces subject to risk of gas leakage must be sufficient ventilated and constantly monitored by gas detectors. The crew are also required to carry gas detectors when entering gas hazardous spaces.

As mentioned before all internal gas piping goes in double walled pipes and the space between is constantly ventilated and monitored for potential gas leakage. The same is also valid for the GVU and the cold box. For the tank room, ventilation of the air volume is
required to be 30 air changes/hour which has been somewhat challenging due to strict noise requirements in the ports.

**Automation and control system**

![Image of main engine performance monitoring at the bridge](image-courtesy-MF-Shipping)

Figure 4.13 Main engine performance monitoring at the bridge (image courtesy MF Shipping).

Automation and control systems related to the LNG-function are in general integrated and allocated to either of the main components like tank installation (Cryonorm), bunker station (Ferus Smit), electrical (Eekels) and LNG engine (Wärtsilä).

![Image of starboard bridge console](image-courtesy-MF-Shipping)

Figure 4.14 Starboard bridge console

Where needed, each subgroup has interfaces to share information e.g. from sensors or control mutual functions or components. The main engine performance monitoring bridge and starboard bridge console are illustrated in Figure 4.13 and Figure 4.14 respectively.
**Electrical installation**

The combination of LNG and cement cargo handling equipment makes M/V Greenland to comparatively complex vessel, this is particular true for the electrical installations. Supply of electrical power, monitoring and control of systems adds complexity and/or extent of:

- Cable routing
- Switchboards
- Interfaces
- Redundancy requirements
- LNG safety zones

Vessels electric power supply is the two dedicated auxiliary engines or main engine driven shaft generator and in emergencies the emergency generator. For particular critical systems supply of electricity is either through UPS and/or emergency generator.

### 4.2.6 Rules and regulations

The ship is built to IMO’s MARPOL and SOLAS regulations and Lloyds Register’s relevant and denoted class rules. According to SOLAS, fuel used on board shall have a flashpoint above 60°C. Obviously LNG is well below this standard requirement which affect ship and machinery arrangements.

**Figure 4.15 Applicable codes and standards (HAZID NB 423, Lloyds register 2014)**

For gas carriers IMO has developed an adopted IGC-code. For ships fuelled by gas, interim guidelines exists (MSC 285(86)). A new code for ships fuelled by gas or other low flash point fuels (IGF) exist in a draft version, but can be used in parallel as guidance. Lloyds Register has developed own rules for gas fuelled ships and subsequently the above mentioned documents is the main standards for the design of this vessel. In addition some other documents are also relevant as references according to the Figure 4.15 ovan. For this type of novelty ship design and LNG arrangement an assessment of risk based design (ARBD) was required. The relevant stages in this process are shown in Figure 4.16.
The first stage in the ARBD process was held at the shipyard in Groningen February 2014. The outcome of this first stage was among other the essential approval in principle for the placement of the tank in the bow. The second stage, also usually referred to as the HAZID (Hazard Identification study) was held in November 2014 over a two day session. The HAZID was done fairly late in the design process which had a certain advantage that the design material is mature but on the other hand any outstanding findings would cause more expensive redesign. In this case the main recommendations were related to the tank connecting space (TCS) and it caused some minor redesign issues among other the introduction of a “cold box” (as described in the LNG storage section) and a sufficient large drip tray to isolate an eventual leak from the surrounding load carrying structure. Some iterations between stage two and three was also necessary during the building time and a general challenge with this type of novelty concept is that it is also new for the regulatory bodies. This builds up a chain of involved persons from local surveyor in Netherlands to central Lloyd’s experts in other countries. In some cases this caused a problematic lead time. Critical components such as the tank had a very short time frame for the desired arrival in order to not involve the sharp 2015-12-31 deadline. It is advisable to arrange a dedicated LNG person from classification society as an access to all issues during the design process.

The stage 4 in the ARBD process was completed 2015-12-08 by the finalization of the HAZOP, focusing on ensuring that the operational procedures for LNG bunkering and operation of the system is mitigating identified risks. The basis for this study was an interactive workshop with relevant experts from ship builder, ship manager, crew and classification society. The common material was the developed procedure, checklists and system documentation. The outcome of this study caused some necessary revisions of the procedures and checklists and also some measurements on hardware level were necessary. The delivery of the vessel was preceded by the full acceptance from class issuing all certificates. For some ports it might be necessary to make additional studies or assessments related to the specific local legislations and constraints to receive permission for bunkering and cargo operations. The ship will mainly load in Rostock (Germany) and Aalborg (Denmark) and transport cement to various harbours along the Swedish and Norwegian coast. It is also planned to discharge in harbours in Lake Mälaren.

### 4.2.7 Vocational training

The introduction of LNG in a dry cargo ship adds a need for training on all levels of the crew. This is also a difference compared to tankers, where the dangerous cargo usually implies a higher educational status on the crew due to the added risks.

Three types of courses were identified as needed, depending on crew role:

- Operating Ships on LNG by Aalesund university
  
  [https://maritime.hials.no/course/24](https://maritime.hials.no/course/24)

  “The course is developed for safe operations of ships designed according to the
IGF code, using Natural gas (LNG) as fuel. The course is designed according to new requirements of the STCW Chapter V - Special training requirements for seafarers on ships using gases or other low-flashpoint fuels. The course meets the requirements of the STCW Convention draft amendment Part A, Chapter V - Special training Requirements given in table AV / 3-1 and AV / 3-2. (ref. HTW 1/21 annex 5)" (https://maritime.hials.no/course/24)

- Basic LNG course including bunkering operations (http://etc.am.szczecin.pl/courses/3-lng.html)
- Wärtsilä engine courses
  Advanced and practical course for the W34DF engine (http://cdn.wartsila.com/docs/default-source/WLSA-files/wlsa-training-programme-catalogue.pdf?sfvrsn=0)

In addition, the crew were in varying extent present at the late stage of the yard phase where they followed the tests at harbour and at sea. This is a very essential period for the crew as a preparation and to familiarize with all systems and procedures, still having close access to the team from yard and vendors.

4.3 Activity 6 – LNG CONV: Conversion of tanker for LNG propulsion

The technical and operational evaluation of Fure West, the Furetank vessel converted for LNG operations is presented in this section. The presentation is focused on the gas fuel system, the main engine and the supporting machinery systems (Table 4-4 and Figure 4.17). The gas fuel system installed at the conversion of Fure West consists of the following main components:

Figure 4.17 Main components of the gas fuel system and their placement, excerpt from GA EDW518-100-01
### 4.3.1 Bunkering stations

Fure West is fitted with two bunker stations, one at each side aft of the LNG-tanks (Figure 4.18). Both bunker stations are connected to both LNG-tanks thus enabling bunkering from both sides. Furetank are expecting about 12-15 LNG bunker operations per year.

![Bunker station on starboard side during installation, without protective cover](image)

The rate of LNG transfer during bunkering will be maximum 300 m³/h at a terminal or bunker vessel and below 100 m³/h when bunkering from a truck. During bunkering LNG-vapour in the tanks can be returned to the bunker stations through pipes, but this is seldom used. There is a spill tray under the bunker stations that is ending at the ship side, and the side will be protected with a curtain of water running down at the ships side. In the case of leakage of a hose the cold LNG will evaporate to air when hitting the water. The bunker stations are connected to the inert gas system for purging of the pipes after bunkering. The bunker stations have been fitted with a fixed powder fire extinguishing systems that will be released from the bunker control station and water sprinkler that can be released in case of a fire.

<table>
<thead>
<tr>
<th>1. Bunker stations</th>
<th>5. Gas valve unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. LNG tanks</td>
<td>6. Engine</td>
</tr>
<tr>
<td>3. Vaporizer unit</td>
<td>7. Ignition fuel unit</td>
</tr>
<tr>
<td>4. Gas fuel pipes</td>
<td>8. Exhaust gas ventilation unit</td>
</tr>
</tbody>
</table>

Table 4-4 Subsystems and supporting machinery
4.3.2 LNG tanks

The initial idea for the conversion of Fure West was to use the boil off gas in the tanks as fuel for the auxiliary engines. At least one auxiliary engine is running all times on the vessel when the main engine is stopped, to provide electricity to the ships systems. The boil off gas could then be used as fuel and the tanks could be built simpler, without extensive requirements on isolation. Since the adaption of the auxiliary engine room for use with gas engines was difficult to accomplish the original plan had to be abandoned. The tanks now had to be capable of holding the gas in a liquid state for longer periods. The volume of the LNG-tanks are 2 x 255 m³. This is the amount of fuel for about 30 days of operation. The LNG-tanks have been designed to hold the liquid gas for 90 days before the pressure from the boil off gas reaches the maximum allowable limit. Maximum capacity and the tanks isolation have been planned to provide for Furetanks intended operation.

The tanks are 27 m long and have a diameter of 4.15 m. The diameter/width was restricted by the maximum allowable height of transport by truck. The tanks were transported from Taylor Wharton in Kosice by truck to Bratislava, river barge to Rotterdam and finally by a coaster to Fayard. The transport was initially planned to be on road only but the weight of the tanks became higher than estimated, 95 tons each instead of 65 tons, which made road transport impossible. The extra weight came in part from the regulation for the marine application that the supplier lacked experience from.

The LNG-tanks are fitted at both ship sides above upper deck between frames #102 and #136. Each tank consists of a cylindrical pressure resisting inner tank, isolated with isolation sheets, Cryotherm, and vacuum. An IMO type-C tank. The inner tank and the isolation is protected by an outer tank, similar to a thermos. Both the inner and outer tanks are made of stainless steel. The two LNG tanks on Fure West are supplied by Caterpillar and built by their sub supplier Taylor Wharton.

The tanks are mounted on deck through supports connected to the ship’s steel structure. In case of a fire hazard on deck the tanks can be cooled with a new installed water sprinkler system that is supplied from the ships ballast system.

LNG is bunkered and stored in the tanks preferably at cryogenic temperature, -162 °C, and atmospheric pressure, but some overpressure, maybe up to 4 bars, can be accepted at bunkering. The temperature of the gas will eventually rise and the LNG will start to boil with a following build of the pressure. The tank is protected from overpressure by an overpressure relief valve. This valve will release at a pressure of 7 bar.
In the most common LNG tank the liquid gas is emptied through the overpressure in the tank. Overpressure is provided by inserting natural gas that have been vaporized in the vaporizer to the required pressure. The tanks on Fure West have been fitted with a submerged pump. With the pump the liquid gas can be pumped out to the vessels fuel system with the pressure that the engine need. The pump makes fuel supply more reliable. The tank can also be emptied by the pump if needed. This is an advantage when docking at a shipyard for repair work, where natural gas is not allowed.

The LNG tank are rather long, 27 meters. When the ship is travelling at sea the liquid LNG may be set to motion by the vessels motions. If the liquids motion, back and forth, coincides with the vessels pitching eigen-frequency the liquid LNG’s motion can cause pressure collapse in the LNG tanks, for vessels with pressurized tanks the engine will switch over to diesel when this occurs, with the pump solution the system are not sensitive to pressure collapses due to that the pressure to the engine are built up by the pump. There is also a benefit for the bunkering and holding time to always keep the pressure as low as possible in the tanks.

### 4.3.3 Vaporizer unit

Liquid gas is led from the tanks through the tank pump to the vaporizer unit. The vaporizer unit converts the gas from liquid phase to gas phase. The vaporization is supported with the vessels internal thermal oil heating system, also used for the general heating on board and cargo heating.

The vaporizer is also designed to handle the vapour from the LNG boil off in the tanks. Through a separate unit of the vaporizer the vapour is compressed and fed via the gas pipe to the engine. The heat source for vaporization comes from the main engine exhausts gas heater and will therefore not require any extra energy.
4.3.4 Gas fuel pipes

The fuel gas is led between the different units in the fuel system by two types of pipes, both made stainless steel qualities (Figure 4.20).

Gas pipes through the heat exchanger room and in the engine room have to be protected from gas leakage. They are of double walled type, two concentric pipes separated by a metal coil. The void between the two pipes is constantly ventilated. A gas detection system monitors the ventilation air and shuts down the gas supply immediately in case of a gas leak.

Gas pipes on open deck are only isolated. In the case of a pipe rupture any gas leak before emergency shut down will be led to open air. The routing of the pipes is through loops, allowing for thermal expansion and the vessels movement.

4.3.5 Purging system

The purging system allows the different sections of gas pipes to be inerted with nitrogen. Inerting with nitrogen clears fuel systems and pipes from explosive fuel gas. Nitrogen is produced on board with the nitrogen gas generator in the forward store and is stored on deck in a pressure vessel.

4.3.6 Gas valve unit

The gas valve unit in the engine room provides the engine with fuel gas at the right volume and pressure for the desired operation. The gas valve unit is placed inside an air tight housing (Figure 4.21). The housing is ventilated continuously. Any gas leakage will be detected immediately and the gas supply will be shut down.
The gas valve unit also performs a leak-tightness-check prior to the start of the engine or a switchover from diesel to gas mode. In the case of a gas fuel shut down the gas valve unit will purge the fuel gas system with inert gas.

The entire GVU is closed with a housing. The housing is ventilated and any gas in the ventilation air is detected by sensors.

4.3.7 Emergency shut down valves

The different sections of the gas fuel system is fitted with a number of emergency shut down valves. These are either shut manually or automatically. Automatic shutdown will be done by the monitoring system in the event of a fuel leak in the double piping or in the ventilation. The fuel system is also fitted with a master gas shut off valve, directly after the vaporizer unit.

Figure 4.21 The gas valve unit during installation, with open housing.

4.3.8 Ignition fuel unit

Gas fuel will not ignite at compression like in a diesel fuel engine. The ignition of the gas fuel is triggered by injection of a small amount of diesel (MGO) at high pressure in the cylinder head. Fuel injection is done via a common rail system.

4.3.9 Gas engine

At the conversion of Fure West at Fayard the main engine was converted into a Caterpillar/MAK 7M46DF dual fuel engine has been installed. The engine is converted from a diesel engine to a dual fuel engine. The engine conversion has been made by Caterpillar/MAK and the installation work has been performed by Pon Power. The former engine was a 7M43-C. Most parts of the engine has been changed or have been modified during the conversion. The engine block and the crankshaft are the same.
The conversion was possible to perform on this particular engine type, C-type. The conversion of the engine made the maximum power output the same as before conversion, 6,300 kW at 500 rpm. The total mass of the engine did not change after the conversion, 107 tons.

The fuel gas is injected by the gas valve unit to the engines cylinders via the fuel gas inlet rail (Figure 4.22).

Any disturbance in the fuel gas supply, like a pipe leak or system malfunction, will immediately switch the engine to diesel-mode. The engine will continue to run on diesel supplied by the vessels original diesel tanks. This switch over is seamless without any loss of engine power, making the system redundant and reliable.

With the engines possibility to run on diesel the operation of the vessel is assured since the availability of LNG-fuel is not yet fully developed in the region of the Baltic and North Sea.
Fure West was fitted with a SCR-system, selective catalyst reduction, already prior to the conversion. The SCR brings the exhausts NOx content down with use of urea, turning the NOx into nitrogen and water vapour. The SCR will remain on board and can be used when the engine is running on gas fuel or diesel.

4.3.10 Safety

The installation of the gas fuel system had to comply with a number of different rules and regulations. There is a large amount of regulations for a LNG installations on ships. The major regulations for the Fure West conversion are:

- Bureau Veritas, Nr.529 Safety rules for gas-fuelled engine installations in ships
- IMO IGC Code, International code for Gas-Carriers

Fure West is built to Bureau Veritas classification rules for construction of ships.

A risk analysis identification workshop, HAZID, was performed in December 2014 in Paris.

The HAZID workshop resulted in a total amount of 89 recommendations on the installation. The recommendations was a basis for follow-ups to mitigate risks during the conversion and following operation of Fure West.

The HAZID performed was appreciated as a good way to identify all necessary modification, from all aspects with the parties involved. The resulting recommendations constituted an action list to follow during the conversion.

Before bunkering at a terminal or from a ship the compatibility between the two parties has to be assessed. This includes mooring systems, bunker transfer systems, communications, emergency shut down systems etc.

Bunkering procedures has to be developed and HAZOPs, Hazard and Operability assessments, also has to be performed prior to bunkering.

4.3.11 Lessons learned from the conversion

Arrangement

During the planning of the conversion of Fure West one aim was to not to impair the vessels existing arrangement in too large extent. It would be of great advantage if the LNG-equipment, especially the LNG-tanks, could be installed without changing the arrangement on board. For example, having to move an access opening to a cargo tank would mean also having to move ladders and platforms in the cargo tank with large amounts of welding and recoating. Keeping the necessary modifications as small as possible saves money. Furetank and designer FKAB managed to redesign the vessel with only small amounts of rearrangements.

Tank placement

One special challenge during the conversion was the placement of the large LNG-tanks. The tank supports had to be fitted to corresponding firm structural members on deck. On single deck we had not and the sufficient strength to carry out the load so two web frames
was connected with intermediate foundations so the load from each of the tank foundations was split between the two deck web frames.

![Image](image_url)

**Figure 4.23** Forward LNG-tank supports at frame #126 during installation,

The aft supports of the tanks are bolted fixed to deck. The forward supports are fixed with an allowance for longitudinal translations (Figure 4.23). This is necessary as the ships structural girder will bend during loading and when travelling in heavy seas.

**Hazardous area**

A ship with gas fuel will be divided in hazardous areas where an explosive gas atmosphere is or may be expected to be present. The hazardous areas are divided in zones following the probability of gas being present in that particular area (Figure 4.24).

Converting Fure West to a LNG-fuelled vessel was facilitated by the vessels original design. As a chemical- and oil product tanker the vessel was already fitted into hazardous areas and for safe handling of explosive gases. The additional requirements following the change of fuel were easier to comply with than what would have been the case if the vessel would not have been a tanker.

The dangerous areas covered almost the entire part of the upper deck prior to the conversion. The installation of a gas fuel system enlarged the zones to some extent, but within limits that could be handled without any large impacts on the vessels arrangement or use.
Equipment on deck within the dangerous zones were explosion proof, EX-classed, prior to the conversion. New equipment installed during the conversion follows the same requirements.

Figure 4.24 Extension of gas zone due to LNG, red, compared to original gas zone, blue, excerpt from EDW518-103-09-02

New dangerous gas zones were added at the funnel and at the front and port side of the superstructure. These are outlets from the crankcase ventilation, at the funnel, and from the ventilation of the engine and the gas valve units, at the sides.

During the design of the new LNG-fuel systems and during the conversion at Fayard shipyard it has become evident that it is not trivial to convert a diesel fuelled ship to a gas fuelled. Components of the gas fuel system are bulky and hard to fit in the vessel. The necessary space for the components has been a challenge to find. The compartment on Fure West are not regarded as being cramped, but with the large size of some of the new equipment suitable placements have been hard to find. During the design of the vessel a few rearrangements had to be made to be able to fit the equipment.

Size of equipment

The gas valve unit installed in the engine room is large (Figure 4.25). The gas valve unit is housed in an airtight pressure resistant housing, making it even larger. During the design of the new machinery system it was difficult to find a suitable place for the unit. The gas valve unit is a bit oversized for the MAK7L46DF engine. It is designed to provide a larger engine with fuel, a MAK 46DF 16-cylinder engine. All components that is a part of the engine delivery is type-approved with the classification society. The present GVU was the smallest type-approved size available. As LNG-fuelled ships will become more frequent more equipment and types/sizes of equipment will be type-approved enabling smaller equipment to be chosen.

Figure 4.25 The gas valve unit during installation, with open housing,
**Fire extinguishing system at bunker station**

The requirements from the IGF code resulted in that the bunker stations has been fitted with fixed powder fire extinguishing systems. Water should not be used as it increases the vaporization. The extinguishing system is supplied by 175 kg of dry chemical powder, stored in the pipe tunnel, and driven by N₂-gas. The dry powder can be released to either of the starboard or port bunker stations.

Furetank is of the opinion that the extinguishing system might as well be fitted as a central station fitted in the centre between the two bunker stations with a hose on a reel. Such an extinguishing system could serve both bunker stations as well as serve as an extinguishing system for other purposes.

According to Furetanks investigations the proposed system would be less expensive and more versatile. The proposed extinguisher system could not be accepted though, as it did not fulfil regulation requirements.

**Ship stability**

With the LNG-tanks placed above the weather deck the ships stability will be a concern. A total of about 210 tons of new equipment has been added during the ships conversion. The majority of the weight has been added at a high positions in the forward part of the ship. With the weight of the LNG-fuel added the total amount of added weight is about 440 tons. With the new LNG-equipment the centre of gravity has moved about 1 m forward and 21 cm upwards, 46 cm taking the weight of the LNG-fuel into account (Figure 4.26). To be able to handle this quite large increase of the vertical centre of gravity two ballast tank pairs had to be modified. These are ballast tank no. 6, forward of the deckhouse, and no. 3, about mid ship. These ballast tanks had to be rebuilt with a void/cofferdam below the cargo tanks. The modification has not lowered the vessels vertical centre of gravity, but has reduced the effect of free liquid surfaces, which has a comparable effect. The modification was necessary to meet the MARPOL regulation 27 for Intact stability in port. The result is about 800 m3 less ballast capacity.

With the modification of the ballast tanks the ship will be able to carry the same amount of cargo as prior to the conversion, about 18860 m3, but the deadweight will be slightly reduced, but this has no practical impact for most of the cargoes. The disadvantage of reducing the volume of the ballast tanks will be slightly reduced draft in ballast condition.

*Figure 4.26 Ballast tank no.3 modification, original-left, modified-right, excerpt from GA EDW518-100-01*
4.3.12 Operational aspects

Fure West has not been tested at sea with the new gas fuelled engine at the writing of this report. Furetank and the crew of the vessel has not yet been given the opportunity to gain knowledge and experience from actual operation with gas fuel. Thus the following description on operational aspects are as the company and the crew foresees the future operation of the vessel, from their best knowledge today.

The change of fuel on Fure West will not have an impact on the size of the crew. The daily operation will still be done by twelve crew members. The engineers on Fure West do not foresee any dramatic changes in their daily work. Their expectations on the oncoming operation and maintenance of the new systems are more or less ‘business as usual’. The all crew will have to undergo mandatory training. Necessary training to due to change of fuel type is set by STCW, Standards of Training, Certification and Watch keeping. Senior officers will participate in training and ratings on Fure West will be trained on board, by the engineers.

**System monitoring**

One concern by the crew for the future operation is the increase of sensors and signals processed with the new engine and the fuel systems. The new installation has about 900 signals that are continuously monitored and controlled. This is a huge increase compared to the signals from the old installation that used about 50. The signals are picked up by sensors and routed by cables (Figure 4.27). The electrical work at the yard has also been more complicated than estimated.

![Figure 4.27 Engine control unit being fitted in the engine room](image)
Availability of LNG fuel

Distribution of LNG-fuel is not yet fully developed in the region of the North Sea and the Baltic, the main areas of operation for Fure West. LNG-bunker terminals for ships are however planned and under construction in the region, like at Brofjorden in Sweden and Hirtshals in Denmark. It seems to be good interest for supplying LNG in the future, but the investments are careful at the moment. The solutions preferred are bunkering from trailers or gas containers on shore instead of dedicated terminals. The gas infrastructure development is also slowed down by authorisation process by the ports.

Bunker vessels for ship to ship bunkering of LNG-ships are also planned. Shell intends to provide LNG to ships in Rotterdam with a bunker vessel currently under construction at Mitsubishi in Japan. Sirius Veder Gas AB, a joint venture between Antony Veder and Sirius shipping, are currently building a LNG-bunker vessel at Royal Bodewes in the Netherlands. The bunker vessel is also a TEN-T project, JIP Flexi. The vessel is planned to provide LNG in the Gothenburg/Skaw area.

Even without an existing infrastructure for LNG-fuel today, Furetank are hopeful for the near future and are currently in discussion with providers of LNG-fuel. In the event that provision of LNG-fuel cannot be granted at the start of the operation of the vessel, it will still be able to run on MGO.
The environmental performance of the new built and converted vessels are presented in this section. In the case of the conversion, the comparison is made with the same vessel before conversion to LNG propulsion. For the new builds, the new vessel is compared to a reference vessel that runs on MGO.

5. Environmental evaluation of LNG technology

This section is devoted to sub-activity 7.2: “Environmental evaluation of LNG Technology”.

Within the ZVT a Joint University Project, Zero.8, is engaged to assess and evaluate benefits to society and sea when JIPs invests in new, green technology. So far they have measured air component but several areas are to be included (to find out more please see www.zerovisiontool.com). JUP Zero.8 was engaged to do this evaluation within Pilot LNG, where three activities have been chosen and are evaluated below. They are different enough, both in process as well as the final result, that the evaluations may not be fully comparable between themselves, even though every effort is made to minimise this deficiency.

Activity 2 the JIP FLEXI and its bunker/feeder vessel, is a wholly new component in the system which neither replaces an existing vessel nor could it feasibly be build running on conventional fuel. This leads to an evaluation where the comparative elements are performed with regards to an illustrative point of reference that does not have any empirical validity.

Regarding activity 5 the JIP LSR and its LNG fuelled dry cargo vessel, the choice of fuel is a central consideration and ample historical data exists to allow reasonable comparison with a feasible reference vessel running of conventional fuel. However, these results are not fully comparable with the ones regarding activity 6 the JIP LNGCONV with the converted vessel, where comparative analyses are made between the performance of the same vessel before and after the conversion.

The environmental performance of the LNG technology implemented in this project is evaluated by estimating the reduction of external costs following reduced air pollutants and greenhouse gases that result from the use of the new technologies. External cost is a concept used by environmental economists to capture – in monetary terms – the environmental and health impacts of consumption and production that are not included (compensated for) in the price of the goods or services produced. Environmental degradation and human health impacts from air pollution are typical examples of external costs.

Reduction of external cost, whether it is achieved through internalization or binding legislation or other means translates into a societal benefit which follows either the more correct allocation of cost (internalization) or reduction of external cost in real terms (higher environmental performance). In this section, these costs are estimated and a comparison is made between the vessels utilizing LNG technology in this project conventional vessels. The vessels used as a point of comparison with the LNG technology are SECA compliant i.e. they are assumed to run on Marine Gas Oil (MGO).
5.1 Methodology

![The main steps of an impact pathway analysis](image)

Figure 5.1 The main steps of an impact pathway analysis (Bickel and Friedrich, 2005)

The analysis is performed in two steps. First, the real values for different pollutants and emissions are calculated for the LNG ships and their conventional counterparts. Secondly, these emission values are monetised in order to arrive at the external cost and enable the comparison of different technologies in this respect. The methodology for these calculations and analyses are presented below.

The Impact Pathway Approach is used to calculate the external costs of the air pollutants from ships. The Impact Pathway Approach is presented in (Bickel and Friedrich, 2005) and is illustrated in Figure 5.1 ovan.

In this study, the emission levels are calculated using the information available from the ship owners. The air pollution emissions from a single ship are scaled up so as to correspond to an entire fleet of ships, and the emissions are introduced into the GAINS model. The GAINS model is then used to calculate emission dispersion and concentration at receptor sites.

The ARP model, and the dose-response functions within, is then using the results from the GAINS model to calculate the impact on human health and the monetary values of these
impacts. We then add on monetary valuations of impacts on crop production and on climate change outside of the models.

5.1.1 Calculating emissions

In order to calculate the emissions from the different ships data was collected from the ship-owners. A number of common parameter values that are used for the projects are presented in Table 5-1 nedan.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ equivalent for CH₄</td>
<td>-</td>
<td>25</td>
<td>IPCC (2013)</td>
</tr>
<tr>
<td>CO₂ equivalent for N₂O</td>
<td>-</td>
<td>298</td>
<td>IPCC (2013)</td>
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<td>-</td>
<td>0.867</td>
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<tr>
<td>C-content LNG</td>
<td>-</td>
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<td>Brynolf (2014)</td>
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<tr>
<td>C-content MeOH</td>
<td></td>
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</tr>
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<td>ppm</td>
<td>1000</td>
<td>Maximum allowed value</td>
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<td>S-content LNG</td>
<td>ppm</td>
<td>5</td>
<td>Brynolf et al. (2014)</td>
</tr>
<tr>
<td>S-content MeOH</td>
<td>ppm</td>
<td>5</td>
<td>Brynolf et al. (2014)</td>
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<tr>
<td>Heat content LNG</td>
<td>MJ/kg</td>
<td>48</td>
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<td>Heat content MGO</td>
<td>MJ/kg</td>
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<tr>
<td>Heat content MeOH</td>
<td>MJ/kg</td>
<td>20</td>
<td>Brynolf et al. (2014)</td>
</tr>
</tbody>
</table>

Table 5-1 Common data used in the emission calculations

It should be emphasised that the data was collected before the projects were finalised and thus many of the parameter values are based on engine specifications and assumptions. Data was collected on fuel consumption (specific for the engines or predicted yearly values), fuel types, engine details, emission factors and planned traffic patterns. Other parameter values were taken from the literature. Emissions calculated were nitrogen oxides (NOₓ), sulphur dioxide (SO₂), particulate matter (PM) and greenhouse gases – carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). The emissions of greenhouse gases are presented in CO₂-equivalents.

5.1.2 Calculating external costs

The impacts from air pollution can rarely be assigned to one single point source of emissions, but the burden sharing of total air pollution impacts can easily be distributed among the sources following their relative contribution to air pollutant emissions. In other words, environmental and health impacts from the emissions of one single ship are impossible to verify, but the environmental and health impacts from all the ships in the North and Baltic sea are, and one single ship’s contribution to this impact is proportional to its relative share of emissions. In this study we scaled up the calculated annual emissions
with a factor of 10,000 prior to introducing the emissions into the models in order to improve the accuracy.

The different emissions for the sea regions lead to different health impacts. With the online\(^3\) version of the GAINS model (Amann, 2011) we calculate population weighted PM2.5-exposure for each European country that would follow from the scenario-specific shipping emissions. The PM2.5 concentration in ambient air is caused by primary PM2.5 emissions, but it is also caused by emissions of NO\(_X\) and SO\(_2\) since these form secondary PM2.5 during their residence time in the air. The country-specific population-weighted PM2.5 exposures are then introduced to the Swedish version of the economic valuation tool ARP (Holland et al., 2013) for further calculation and monetary valuation of health impacts. After having calculated the total monetised health impact of the scenarios, the values are scaled down by a factor of 10,000 in order to get an impact corresponding to the actual emissions from the ships. Furthermore, the economic valuation of health impacts was complemented with economic valuation of reduced CO\(_2\) emissions and crop losses in the affected regions.

The health impact with highest monetary value is avoided mortality (fatality), which is valued by either estimating the Value of Statistical Life (VSL) or the Value Of Life Year lost (VOLY). The estimated economic values of VSL and VOLY vary in the literature and between methods. The values can also differ due to differences in how many life years that are assumed to be lost when a fatality occurs. We therefore include low, mid and high values in the results below. Low values imply that the valuation of avoided mortality is based on the median VOLY estimate from Desaigues et al. (2011); mid values represent the use of the median VOLY estimate according to Friedrich (2004) and Hurley et al. (2005); whereas high values represent the use of the mean VSL value according to OECD (2012). In the proposal for the new EU Clean Air Policy Package published on the 18th of December 2013 (European Commission 2013), values corresponding to the mid values were used. Table 12 presents the values for VSL and VOLY used in the monetization of health impacts. The health impacts from air pollution are specified by the use of exposure-response functions, and in our analysis we have used values from the WHO/EU Health Risks of air pollution in Europe (HRAPIE) project (WHO, Henschel and Chan, 2013, Holland, 2014, Heroux et al., 2015).

<table>
<thead>
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<td>Friedrich, 2004, Hurley et al., 2005</td>
</tr>
</tbody>
</table>

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\(^3\) [http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1](http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1)
health impact improvements and reduced crop damages are found for all cases. When we
By using the same monetary values for human health and crop damage impacts as used by
Furthermore, the use of LNG is associated with reduced CO\textsubscript{2} emissions.

<table>
<thead>
<tr>
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<th>Impact</th>
<th>Valuation (€\textsubscript{2010})</th>
<th>Data source</th>
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</tr>
<tr>
<td>Infant Mortality (0-1yr) mean VSL</td>
<td>Premature deaths</td>
<td>3’721’941</td>
<td>Friedrich, 2004, Hurley et al., 2005</td>
</tr>
</tbody>
</table>

Table 5-2 Economic values of VOLY and VSL used in this analysis.

There are a number of additional health impacts from air pollution, such as bronchitis, cardio-vascular and pulmonary diseases, as well as restricted activity, but since the economic impact of these are smaller than the impact of avoided mortality they have been omitted from the table ovan.

Crop damage is valued per tonne of NO\textsubscript{X} emissions from each sea region. NO\textsubscript{X} is one of the substances needed for the formation of ground-level ozone, which in turn causes damage to crops. The economic valuation of these damages is based on aggregate market prices for a number of crops. NO\textsubscript{X} emissions from the Baltic Sea are associated with crop damages corresponding to ~146 €2010 / tonne NO\textsubscript{X}, while NO\textsubscript{X} emissions from the North Sea are associated with crop damages corresponding to ~35 €2010 / tonne NO\textsubscript{X} (Holland et al., 2011).

<table>
<thead>
<tr>
<th>Range</th>
<th>Value</th>
<th>Unit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>6.7</td>
<td>€\textsubscript{2010}/tonne CO\textsubscript{2}</td>
<td>Current (Dec. 2014) EU ETS market price\textsuperscript{2}</td>
</tr>
<tr>
<td>Mid</td>
<td>24</td>
<td>€\textsubscript{2010}/tonne CO\textsubscript{2}</td>
<td>(Stern 2006), 450-550 ppm world ($30 / tonne CO\textsubscript{2})</td>
</tr>
<tr>
<td>High</td>
<td>70</td>
<td>€\textsubscript{2010}/tonne CO\textsubscript{2}</td>
<td>(Stern 2006), BAU world ($85 / tonne CO\textsubscript{2})</td>
</tr>
</tbody>
</table>

Table 5-3 Economic values per tonne of CO\textsubscript{2} emission used in this analysis.

Furthermore, the use of LNG is associated with reduced CO\textsubscript{2} emissions that also have a monetary value. Using economic values from the EU ETS market and the Stern report (Stern, 2006), a range of external costs of CO\textsubscript{2} can be estimated. The economic values analysed for CO\textsubscript{2} are listed in Table 5-3 ovan.

By using the same monetary values for human health and crop damage impacts as used by the European Commission, but updated to €2010 exchange rate, significant monetary health impact improvements and reduced crop damages are found for all cases. When we
add values for external costs of CO₂ emissions, the monetized effect is further increased. This monetary benefit is a total of the benefits for all European countries affected by reduced emissions in the Baltic Sea and in the North Sea and English Channel for a single ship of the types considered. These values are understatements of the external costs associated with our cases since the actual ship routes are located in densely populated areas, while the GAINS model provides results for an average emission reduction for a sea region.

The difference in external costs between a SECA compliant conventional ship and the ships using LNG technology are calculated below. This difference is equal to the benefits for Europe of the reduced emissions.

5.2 Activity 2 – JIP FLEXI: a bunker/feeder vessel

Considering how the bunker/feeder vessel is a new build that is not replacing an existing ship and also the fact that it would be unlikely for any ship owner to new build an LNG bunker/feeder vessel to operate primarily on conventional fuels, the comparison below needs to be approached with care. The vessel is an indispensable component of a maritime transport system that is to be operated on LNG as a fuel. It in some respect enables the realization of the benefits produced in replacing conventional fuels with LNG in this segment. The calculations below are produced in order to illustrate the environmental performance of this vessel in a comparable way with regards to the other ships included in Pilot LNG.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Flexi</th>
<th>Ref.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO consumption</td>
<td>Tonnes/year</td>
<td>112</td>
<td>2891</td>
<td>Calculated from fuel energy content</td>
</tr>
<tr>
<td>LNG consumption</td>
<td>Tonnes/year</td>
<td>2461</td>
<td>0</td>
<td>Calculated from fuel energy content</td>
</tr>
<tr>
<td>SFC LNG ME</td>
<td>g/kWh</td>
<td>154</td>
<td>-</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC MGO ME</td>
<td>g/kWh</td>
<td>1.5</td>
<td>174</td>
<td>Corresponds to 1% MGO for LNG ship</td>
</tr>
<tr>
<td>EFNOX ME</td>
<td>g/kWh</td>
<td>2</td>
<td>13</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC MGO AE</td>
<td>g/kWh</td>
<td>205</td>
<td>205</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC LNG AE</td>
<td>g/kWh</td>
<td>174</td>
<td>-</td>
<td>Ship owner</td>
</tr>
<tr>
<td>EFNOX LNG AE</td>
<td>g/kWh</td>
<td>2</td>
<td>2</td>
<td>Ship owner</td>
</tr>
<tr>
<td>EFNOX MGO AE</td>
<td>g/kWh</td>
<td>8.5</td>
<td>8.5</td>
<td>Assumption</td>
</tr>
<tr>
<td>EFPM2.5 ME, LNG AE</td>
<td>g/kWh</td>
<td>0.05</td>
<td>0.4</td>
<td>Anderson et al. (2015)/Cooper and Gustafsson (2004)</td>
</tr>
<tr>
<td>EFPM2.5 AE MGO</td>
<td>g/kWh</td>
<td>0.4</td>
<td>0.4</td>
<td>Cooper and Gustafsson (2004)</td>
</tr>
</tbody>
</table>
Table 5-4 Data used in the emission calculations for Flexi

This bunker/feeder will have the Skagerrak/Kattegat region as its operating area. The ship has a dual fuel main engines and both MGO and LNG fueled auxiliary engines. It is compared to a reference ship (Ref.) with the same yearly fuel consumption (calculated as energy content in the fuel) running on MGO. The data used in the calculations are presented in Table 5-4 with the resulting emission in Table 5-5.

Table 5-5 Resulting annual emissions and fuel use for Flexi

Table 5-6 shows the results of changes in external costs for Flexi. The new LNG-fuelled ship is compared with the performance of a similar ship running on MGO. The changes in external costs are calculated for an operating profile where the vessel is sailing 80% of the time in the North Sea and 20% in the Baltic Sea.

Table 5-6 Difference in external costs (thousand €2010 - per year) of reduced health impacts and crop losses in 2015 associated with the Flexi when compared to conventional reference ship
5.3 Activity 5 – JIP LSR: an LNG fuelled dry cargo vessel

The JIP LNG Sea River (LSR) project involves a dry cargo ship converted to use LNG in a dual fuel engine together with 3% MGO. The data used for the emission calculations are presented in Table 5-7. The alternative ship (Ref.) is a similar ship running on MGO, with the same yearly fuel consumption (calculated as energy content in the fuel).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>LSR</th>
<th>Ref.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO consumption</td>
<td>Tonnes/year</td>
<td>278</td>
<td>1963</td>
<td>Calculated from fuel energy content</td>
</tr>
<tr>
<td>LNG consumption</td>
<td>Tonnes/year</td>
<td>1600</td>
<td>0</td>
<td>Calculated from fuel energy content</td>
</tr>
<tr>
<td>SFC LNG ME</td>
<td>g/kWh</td>
<td>161</td>
<td>-</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC MGO ME</td>
<td>g/kWh</td>
<td>5</td>
<td>185</td>
<td>Corresponds to 3% MGO for LNG ship</td>
</tr>
<tr>
<td>EFNOx ME</td>
<td>g/kWh</td>
<td>2</td>
<td>13</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC MGO AE</td>
<td>g/kWh</td>
<td>205</td>
<td>205</td>
<td>Assumption</td>
</tr>
<tr>
<td>EFNOx AE</td>
<td>g/kWh</td>
<td>8.5</td>
<td>8.5</td>
<td>Assumption</td>
</tr>
<tr>
<td>EFPM2.5 ME</td>
<td>g/kWh</td>
<td>0.05</td>
<td>0.4</td>
<td>Anderson et al. (2015)/Cooper and Gustafsson (2004)</td>
</tr>
<tr>
<td>EFPM2.5 AE</td>
<td>g/kWh</td>
<td>0.4</td>
<td>0.4</td>
<td>Cooper and Gustafsson (2004)</td>
</tr>
<tr>
<td>EF CH₄ ME</td>
<td>g/kWh</td>
<td>1.7</td>
<td>0.004</td>
<td>Brynolf et al. (2014)</td>
</tr>
<tr>
<td>EF CH₄ AE</td>
<td>g/kWh</td>
<td>0.004</td>
<td>0.004</td>
<td>Brynolf et al. (2014)</td>
</tr>
</tbody>
</table>

Table 5-7 Data used in the emission calculations for LSR

In order to do the impact assessment an assumption has to be made on the split of the ships’ traffic between the Baltic and North Seas. This is done assigning 50% of the traffic to the Baltic Sea and 50% to the North Sea based on information from the ship owner. The resulting yearly emissions are presented in Table 5-8.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LSR</th>
<th>Ref. ship</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ eqv</td>
<td>5300</td>
<td>6200</td>
<td>Tonnes</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.50</td>
<td>3.9</td>
<td>Tonnes</td>
</tr>
<tr>
<td>NOx</td>
<td>27</td>
<td>131</td>
<td>Tonnes</td>
</tr>
<tr>
<td>PM2.5</td>
<td>0.85</td>
<td>4.2</td>
<td>Tonnes</td>
</tr>
<tr>
<td>Parameter</td>
<td>LSR</td>
<td>Ref. ship</td>
<td>Unit</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----</td>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>Fuel use</td>
<td>83</td>
<td>83</td>
<td>TJ</td>
</tr>
</tbody>
</table>

Table 5-8 Resulting annual emissions and fuel use for LSR

Table 5-9 shows the results on changes in external costs for the vessel. The new LNG-fuelled ship is compared with the performance of a similar reference ship running on MGO. The change in external costs for health risks is the dominant term.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flexi v Ref. ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Health, low</td>
<td>264</td>
</tr>
<tr>
<td>Human Health, mid</td>
<td>344</td>
</tr>
<tr>
<td>Human Health, high</td>
<td>1315</td>
</tr>
<tr>
<td>CO₂, low</td>
<td>6</td>
</tr>
<tr>
<td>CO₂, mid</td>
<td>22</td>
</tr>
<tr>
<td>CO₂, high</td>
<td>63</td>
</tr>
<tr>
<td>Crop damage</td>
<td>9</td>
</tr>
<tr>
<td>Total, central (low-high)</td>
<td>375 (280-1388)</td>
</tr>
</tbody>
</table>

Table 5-9 Difference in external costs (thousand €2010 - per year) of reduced health impacts and crop losses in 2015 associated with the LSR-LNG when compared to the alternative reference ship running on MGO.

5.4 Activity 6 – JIP LNGCONV: Conversion of tanker for LNG propulsion

The JIP LNGCONV involves a tanker converted to use LNG in a dual fuel engine. The data used for the emission calculations are presented in Table 5-10. The alternative reference ship (Ref.) is a similar ship running on MGO, with the same yearly fuel consumption (calculated as energy content in the fuel).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Conv.</th>
<th>Ref.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO consumption</td>
<td>Tonnes/year</td>
<td>442</td>
<td>2621</td>
<td>Ship owner/ assumption</td>
</tr>
<tr>
<td>LNG consumption</td>
<td>Tonnes/year</td>
<td>1959</td>
<td>0</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC LNG ME</td>
<td>g/kWh</td>
<td>169</td>
<td>-</td>
<td>Ship owner</td>
</tr>
<tr>
<td>SFC MGO ME</td>
<td>g/kWh</td>
<td>8.9</td>
<td>187</td>
<td>Corresponds to 5% MGO for LNG ship</td>
</tr>
<tr>
<td>EFNOx ME</td>
<td>g/kWh</td>
<td>0.5</td>
<td>13</td>
<td>Ship owner</td>
</tr>
</tbody>
</table>
Table 5-10 Data used in the emission calculations for LNGCONV

The detailed traffic patterns expected for the vessel are not known. In order to do the impact assessment an assumption has to be made on the split of the ships’ traffic between the Baltic and the North Sea. An assumption is made that the vessel sails 65% of the traffic to the Baltic Sea and 35% to the North Sea. The resulting yearly emissions are presented in Table 5-11.

Table 5-11 Resulting emissions and fuel use for LNGCONV

Table 5-12 shows the results on changes in external costs for the JIP LNGCONV vessel. The rebuilt LNG-fuelled ship is compared with the performance of the ship when running on MGO before the rebuilding of the engine. The change in external costs for health risks is the dominant term.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flexi v Ref. ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂, low</td>
<td>7</td>
</tr>
<tr>
<td>CO₂, mid</td>
<td>26</td>
</tr>
<tr>
<td>CO₂, high</td>
<td>77</td>
</tr>
<tr>
<td>Crop damage</td>
<td>19</td>
</tr>
<tr>
<td><strong>Total, central (low-high)</strong></td>
<td><strong>544 (409-2002)</strong></td>
</tr>
</tbody>
</table>

Table 5-12 Difference in external costs (thousand €2010 - per year) of reduced health impacts and crop losses in 2015 associated with the LNGCONV ship when compared to the alternative ship.
6. Financial evaluation of using LNG as fuel

6.1 Background

LNG carriers excluded, LNG has been used as a marine fuel for ships since year 2000 when the Norwegian road ferry MF Glutra was put into service. Since then the technical and operational development of using LNG as a marine fuel has been tremendous bolstered among others by significant public support. The main hypothesis driving this development has been that LNG had the potential to combine an improved environmental performance of shipping with a competitive cost level. The introduction of stricter emission regulations for international shipping through the revised MARPOL Annex VI as well as a number of regional and local initiatives also drove the interest to use LNG as a marine fuel.

Today LNG as a fuel is both a proven and available commercial solution. LNG offers advantages, especially for ships in the light of ever-tightening emission regulations. Whilst different technologies can be used to comply with air emission limits, LNG technology is the only option that can meet existing and upcoming requirements for the main types of emissions (SOx, NOx, PM, CO2). In most market conditions LNG can be competitive pricewise with distillate fuels and unlike other solutions do not require the installation of additional abatement technologies.

At the same time, the development in the period 2012 to 2015 has not been as forecasted by a number of players such. According to the participants of the Pilot LNG the primary reason for this has been financially related.

According to Pilot LNG beneficiary Donsøtank there is per today 75 LNG fuelled vessels in operation worldwide. In addition there is 84 confirmed LNG fuelled new buildings ongoing as well as 159 confirmed LNG fuelled ship projects worldwide.

6.2 Financial and technical challenges with LNG distribution

LNG is natural gas handled as a liquid at cryogenic temperatures, usually in the range from -150°C down to -163°C. The rule of thumb is that warm LNG has a lower commercial value than cold implying that LNG is a perishable that needs to be handled with care. In applications where it is possible to continuously use the boil of generated due to heat intrusion in the systems for something valuable it is possible to store LNG for some time without financial implication but if not the LNG immediately starts to lose value. This makes trading of LNG complex since it is not possible to put LNG in a storage facility and then wait for the market conditions to improve.

If comparing with the more traditional fuels of shipping such as MGO and HFO it is significantly more complex to handle LNG due to the cryogenic temperatures. The requirements on materials used in the handling equipment, safety arrangements as well as training and competence requirements of the staff dealing with LNG makes each part of a distribution system more costly if comparing it with the different parts used for the distribution of traditional fuels. This makes the barriers to entry high if you want to be a part of the distribution system of LNG making it difficult to challenge the transparent and competitive distributions systems available for the traditional fuels.

Some of the participants in the LNG Pilot focused on providing LNG bunker and feeder vessels to the distribution market have had significant issues to finance the construction of these vessels despite the financial contribution from EU. The banks and financial institutes have been reluctant to do so due to the relatively high cost of the vessels and the dubiety in
their long term commercial value. The reliability of the funding from EU have also been questioned in some of the projects.

To move forward the banks and the financial institutes have required long charter contracts with financially very stable clients. These requirements have made some of the projects within the Pilot LNG impossible to realize and some only after some significant delays due to times related to build commercial structures stable enough to secure the financing. Due to the perceived high risk related to this kind of investments, each part of such deal have added a risk margin increasing the total cost of the project.

Due to the high cost of the distribution assets as well as the technical challenges, the economy of scale is of great importance for the suppliers LNG as well as high utility of the assets in their attempts to reduce the cost per delivered MWh. In general terms, shipping desire flexibility in both delivery time and location, a desire that is contradictory to perspective of the suppliers. According to LNG Pilot Partner Thun the cost and the lack of availability of LNG is the main challenge for them to make LNG a commercially viable choice for their whole fleet.

6.3 Financial and technical challenges using LNG as marine fuel

The traditional marine fuels are stored in simple hull integrated tanks and are distributed in common steel pipes. The engine related fuel systems are rather simple and even if some of the fuels need to be heated and cleaned before consumption, the storage and handling systems are simple. The cost of these systems constitute a minor part of the construction of a vessel.

For an LNG fuelled ship the necessary systems are more complex. The storage tanks usually needs to be construction in stainless steel and the requirements for safety measurements and construction materials related to the internal distribution systems and engines are significant. For LNG fuelled vessel the cost of these systems constitute a significant part of the total cost of the vessel.

The additional cost have to be covered either by an increased willingness to pay by the clients or through reduced cost for fuel and/or operation. In the present market situation, this have been difficult to achieve. As for the bunker/feeder vessels mentioned above there have also been challenges to finance both new building and conversions. The reasons for this have been similar as per the bunker/feeder vessels where the commercial value of the increased investments cost have been questioned by the banks and financial institutes. According to LNG Pilot Partner Furetank increase the challenges even more since the additional cost for Ice class also reduce the competitiveness in the general shipping market.

The implication of this have been that some of the projects within the LNG Pilot have been difficult to realize despite the financial backing from EU.

For the ship owners the difference in price mechanisms between LNG and the traditional fuels as described below also is an issue since they compete with equally sized vessel operation on the traditional fuels. According the LNG pilot partner Furetank a MGO indexed LNG price is important to reduce these differences.

6.4 The decline in the general price of energy

Since mid 2014 there have been a significant downturn in the general energy prices both in Europe and globally. This have also affected the price of the traditional fuel for shipping where the MGO price in Rotterdam has been reduced with ~70% from June 2014 to
January 2016. This decline have had a significant impact on the competitiveness of LNG as marine fuel.

The following principal formula described the basic price setting mechanism for any provider of energy for shipping.

\[
\text{Price delivered}=\text{Sourcing cost}+\text{Distribution cost}+\text{Profit}
\]

The sourcing cost is in principle based on the general price of energy. The natural gas price in Europe, which is the main indicator for the European LNG price have in the period from June 2014 to January 2016 been reduced by approximately 25%. Compared to the decline in MGO this is decline is very limited. This have clearly contributed in the reduction of competitiveness for LNG as marine fuel but the more predominant reason for the lack of competitiveness is actually related to the distribution cost.

As stated, there is a transparent and competitive distribution system for traditional fuel oil. Typical distribution cost for oil products in the main bunker ports in Europe is below 1 EUR/MWh and even in remote ports the distribution cost seldom pass 5 EUR/MWh. For LNG this is different and a reasonable cost of distribution even in the most LNG favourable ports is seldom below 10 EUR/MWh. Since these costs are unrelated to the general price of energy the general competitiveness of LNG benefit from high energy prices. In a low energy price market as the current the competitiveness of LNG are low.

6.5 Conclusions

Despite the present market condition the participants of the Pilot LNG still believe that LNG will have a significant importance as future fuel for shipping, a believe that many within the shipping industry as such seem to share.

Though at present LNG is not able to compete commercially with the traditional fuels for shipping on its own merits. The complex and costly handling systems for LNG in combination with the general decline in the cost of energy have created a situation where it is difficult for any player in the market to motivate significant investments in the LNG as marine fuel market. The situation is equal independently if you are a supplier, a distribution asset provider or a consumer of LNG.

In a global perspective there is continuously new orders registered for LNG fuelled or LNG ready vessels and the availability is increasing even if the pace of these developments are slower than previously expected.

If the present market conditions remain for a longer period, there is a significant risk that the environmental benefits of LNG will not be made available for the society if the development of LNG as marine fuel isn’t continuously supported by the society. This support may come in different forms. It may come as subsidies and investment support, financial risk reducing schemes, differentiated port and fairway dues, stricter environmental legislation for shipping and ports, GHG taxes etc.
The motivation for providing public financial support for the project at hand is explained in this section. The section is concluded by making a case for continued support for followers. Some suggestions regarding the setup of the financial mechanisms are presented.

7. Financial mechanism to establish support for followers

With the objective of supporting followers during the transition into a more safe, environmentally, climate and energy efficient transport at sea the reporting to the ZVTREF have been moving from issues regarding infrastructure and regulations in 2012-2014, to more concern financial implications.

7.1 Costs and early movers

When a company invests in new, innovative or developmental technologies, it increases its initial costs and investment risk considerably compared to investments that lack the uncertainty and cost of developing the necessary technology. In most instances, these types of investments are made based on an expectation that the cost and risk will be outweighed by future revenues and profits, once the technology matures. In business literature, concepts such as “early mover advantage” are discussed in order to illustrate this phenomenon.

Without these conditions; 1) an expected advantage following the investment in developing new or adopting developmental technologies, and, 2) an ability to at a later date offset the additional risks and costs with sufficient increase of revenue, there would not make much economic sense for any company to make these types of investments.

However, in the current context there does not exist an early mover advantage rather the early mover is more likely to be handicapped with an insurmountable disadvantage.

A ship owner or shipping company produces a service. Some of the defining characteristics of services, as compared and contrasted to products, are that services are consumed and produced simultaneously and services once produced cannot be stored. This particular service segment, maritime transportation, is characterized by low margins, high capital requirements, extreme cost focus and cost aware customers who are not willing to pay for anything above what is an acceptable minimum performance and/or quality.

These circumstances taken together leads to the conclusion that any ship owner tasked with an investment decision should only opt for investments that incur low risk and have very short payback time. The low risk requirement follows the low margins and the short payback time the inability to reallocate production capacity and hence revenue potential in time. The cost of any real or potential improvement of a vessel, which in fact would be an upgrade or improvement of the production system of the shipping company, must at least be matched or outweighed by a corresponding decrease in operational cost or increase in revenue potential fairly immediately.

Investing in LNG technology at the time this project was initiated was estimated to increase the investment cost with roughly 25–30%. The increase in cost is driven by a number of factors. Some of the cost increase is due to the efforts to develop and adopt the technology for its intended application. These cost are diminishing over time as the technologies mature and cease to developmental and start becoming off the shelf type of product. Some of the cost is driven by the technical uncertainty related to development of technologies, its reliable production, installation, operation and regulation. These too are diminishing over time as the novel becomes the new norm. Finally, some costs are driven
by the technical solution in and of itself and will likely not decrease any more rapidly than other mature technologies i.e. through the incremental productivity improvements. These costs are estimated to account for more than half of the total cost increase encountered in this project.

However, the earnings potential of the vessels utilizing these new technologies would largely be unchanged. At the time it was forecasted that the operational cost would be marginally to moderately lower. Though the recent developments in the market price of oil and gas have rendered these prognoses essentially inaccurate. Hence the increase in investment cost cannot reasonably be expected to be outweighed by a corresponding decrease in operational cost or increase in revenue. This condition alone is enough to dissuade an investment even if one would to disregard that in order for it to be economically prudent to invest in new technologies, the technical risks that follow the investment should feasibly be outweigh by some future reward. Such is the nature of valuation of risk in business.

Furthermore, the benefit created by investing in these unprofitable technological developments, is largely societal and befall the public at large and not the investors, or its customers, exclusively or even primarily. The proposition is hence for the ship owner to opt to make a loss bearing investment in order to create technological advancement for the shipping industry and environmental value for all. As laudable as this might sound, it does not make for sensible economic strategy for a private company.

In order for the governments of the member states to hasten the improvement of the environmental performance of shipping, as a means to tackle the environmental challenges faced by all, a combination of legislation and financial support for technological development was undertaken. The maximum allowable sulphur content in maritime fuel was reduced with plans to also introduce tighter regulation for nitrogen emissions. At the same time, through the TEN-T vehicle, funds were made available to offset the early mover disadvantage described above. Only doing one of these two measures, i.e. regulation and financial support for development, and waiting for market forces to drive the technological innovation would not have been nearly as time effective due to the specific conditions of this particular business segment.

As progress is made and developmental technologies and its application in shipping matures, the fact remains and given the market conditions prevalent currently and within the foreseeable future, an investment in LNG technology still requires a 10-30% cost increase that cannot be offset by a corresponding decrease in operational cost or increase in revenue.

7.2 Grants, lending and borrowing

Grants and co-funding schemes such as the Motorways of the Sea programme have helped get a number of ZVT related projects off the ground and drive the European maritime sector forward (e.g. Pilot Methanol - the ground-breaking use of methanol as a marine fuel, Pilot LNG - establishment of LNG infrastructure in the Baltics and Pilot Scrubber - tests of closed loop scrubber systems). In time, other types of grants, fees and margins generated by the structure will be included, and is a necessity for new Pilots to take form to continue to drive technology and the market forward.

However, based on the ZVT reporting from all the JIPs, financial instrument, a risk sharing FI, is also seen as a necessity to speed up a transition to a shipping sector with no negative impact in air or water. Shipowners intending to invest in "green" vessels typically rely on the availability of bank loans that can be obtained on the market. A particular difficulty is
the additional cost incurred in the building of e.g. a vessel running on an alternative fuel compared with a conventionally run vessel. When making their risk assessment for any particular loan, banks are often not inclined to provide a loan covering the additional cost of a “green” vessel. From a strictly commercial and financial perspective as mentioned above, current market perception is that this type of investments does not automatically increase the market value of the ship because the ship’s earnings capacity is not automatically proportionately increased as a result of the incremental green investment nor is the second hand value increased. This seriously undermines the market uptake of such vessels. Therefore, to address the barrier to green investment in the sector, a FI structure is needed to share the risks.

The objective of the suggested financial instrument is to (partially) de-risk commercial lenders on their financing of green investments and to calibrate FI resources and pricing on the external benefit of the investments using a consistent, independent and scientific measurement method of the external benefits. The interest rate and related conditions can then for the first time include a component of the overall benefit to the society and the sea (using, among other things, the results from the JUP Zero.8 measurements).

As mentioned in chapter 6 the benefit to the society is in average 1M EUR/vessel/year, in the air emissions perspective alone. That corresponds to an investment done by the industry of 10M EUR in total (calculating that on average this type of vessel in this area operates 15-20 years).

7.3 Gain for society, industry and not least the sea

Within the ZVT there is already now interested parties involved in an application to put forward a structure, and live testing, for such a risk sharing financial instrument. The industry can not, and should not, rely on grants but for Pilots and innovations, when it comes to followers and creating the tipping point into a new normal the risk sharing is therefore suggested. At this stage it is in itself a Pilot but are to be a complement to the grant system when launched.

Another mechanism that also supports the climate and environment goals is when subsidising sectors where shipping, which usually is more energy efficient that land based modes, most immediately faces competition from road and rail in an Eco bonus setup. This approach would have the dual effect of incentivising investments in technologies which higher environmental performance at the same time as it combats so called modal backshift and sustains or even increases the share of transports performed at sea as opposed to land. Fairway due and port fee rebates for higher performing ships is yet another way to offset the disadvantage of delivering a higher environmental performance than what the market is willing to pay for currently. This approach would reallocate cost within the shipping sector and not really offset the larger problem of goods being transported more cheaply using inferior modes of transport with regards to environmental performance. To tackle this issue, measures that would increase the rate of internalisation for land based modes should be considered.
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