LNG AS FUEL FOR INLAND WATERWAY VESSELS

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Defining Business Opportunities of LNG Fuel Systems for Inland Waterway Vessels

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LNG as Fuel for Inland Waterway Vessels

DEFINING BUSINESS OPPORTUNITIES OF LNG FUEL SYSTEMS FOR INLAND WATERWAY VESSELS

By

M.A.P. van den Berg, BEng

in partial fulfilment of the requirements to obtain the degree of

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Some parts have been deliberately masked white, you can contact Cryonorm.

PREFACE AND ACKNOWLEGMENT

With this thesis, all requirements for my graduation in the MSc program in Transport, Infrastructure and Logistics (TIL) at the Delft University of Technology are met. The Master TIL is a multi- and interdisciplinary program jointly offered by the three faculties “Civil Engineering and Geosciences” and “Mechanical, Maritime and Materials Engineering” (3ME) and “Technology, Policy and Management”. This thesis is commissioned by Cryonorm Systems B.V., Alphen aan den Rijn.

In this research, developments of LNG as fuel for inland waterway vessels are explored. This report is intended for Cryonorm Systems B.V. and maritime companies who are interested in LNG as fuel. Hence, it is assumed that the reader has basic understanding of shipping and its associated terminology.

ABSTRACT

Cryonorm Systems B.V. is a designer and supplier of marine LNG fuel systems for both inland and seagoing vessels. The use of LNG as fuel was introduced by seagoing vessels and there is also a propensity to move to LNG as fuel for inland waterway vessels. LNG as fuel for inland waterway vessels is the subject of this investigation.

In this thesis, the business opportunities of LNG fuel systems for Cryonorm are addressed in scenarios for the upcoming 10 years. With this, Cryonorm can eventually adjust their strategy and make decisions on their business model by different scenarios.

The use of LNG as fuel and the LNG supply chain is still in its deadlock, whereby all actors are reserved to invest. A preliminary research on the use of LNG as fuel for inland waterway vessels showed that there is no incentive, what matters, for shipping companies to move to LNG as fuel. Though, temporary subsidies are available for the first movers to use LNG as fuel for inland waterway vessels.

In this research, first, the potential economic profitability and financial feasibility of using LNG as fuel is investigated. The cost items: fuel costs, capital costs and the costs of repair and maintenance are determined, in case of using LNG as fuel in a dual fuel engine configuration. A dual fuel engine configuration has advantages on fuel flexibility and favourable investment costs, hence the best option. It is assumed that these three cost items will mainly alter the total costs of inland shipping. Current fuel prices are in disadvantage for the use of LNG as fuel and considered as uncertain for the future, because of this the fuel costs are considered as a variable. In this report, the required initial additional investment costs to move to LNG as fuel for inland waterway motor tanker or dry bulk vessel are estimated between ,
respectively in range of CEMT class IV to VI. The additional costs of repair and maintenance are gathered by consultation of experts in the field and are incorporated in a business case analysis, which incorporates the net present value of capital and the inland shipping policy parameters of the ABN Amro bank.

The first inland waterway vessels that will be eligible for using LNG as fuel are, out of the business case analysis, are respectively, Koppelverbanden, Large Tankers, and related Large Container Vessels, and probably push vessels. The business case can only start, for these first eligible vessels, if there is a substantial price advantage on LNG as fuel, in terms of €216.- discount per m^3 low sulphur marine gas oil (LSMGO) equivalent, and they have high annual fuel consumption. For the main part of the fleet it can be considered that larger motor vessels are more eligible, based on the main characteristics of the fleet, to potential use LNG as fuel. On the other hand, the total fleet of the Rijn-Hernekanaalschip and Large Rhine Vessels (95 – 135m, mainly 110m) is enormous. Hence, the absolute number of eligible vessels to potentially move to LNG as fuel by these considered vessels is larger. Out of this, it can be expected that if some Rijn-Hernekanaalship and Large Rhine Vessels become eligible to use LNG as fuel, they will rather be retrofitted with an LNG fuel system, due to the low share of vessels that consumes enough.

Secondly, in this research, obstacles and opportunities for using LNG as fuel for inland waterway vessels are investigated. In able to consider LNG as a ready fuel solution for inland waterway vessels, some obstacles will have to be overcome. Besides, opportunities can support or accelerate the use of LNG as fuel. To capture the obstacles and opportunities of importance, as many different facets were explored. The results are presented in a framework of 6 aspects, based on Shell's scenario approach (Shell, 2013), which covers the business environment of fuels. With these framework three scenarios, whereby the business opportunities for

LNG fuel systems becomes positive, are developed and implications out of the scenarios are qualified and examined.

The first scenario, business as usual, is defined by the autonomous developments in the LNG supply chain and the inland shipping market. The autonomous developments are based on subsidy programs and the ongoing developments in the LNG supply chain. The only incentive for shipping companies to move to LNG as fuel is subsidies to overcome the initial investment costs. In case of a port or other governmental bodies, who will use LNG as fuel, they will act as a launching customer. In this scenario, it is expected that waterway vessels will move to LNG as fuel until 2030, mainly by new built.

In the second scenario, the Norwegian NOx fund is used as an example. By the NOx fund extra taxation, based on the NOx emission, covers initial investments for cleaner shipping. This scenario can only be achieved if the Mannheim Convention is no longer applicable, though legally difficult to realise. (KIM, 5/2015) Introduction of the NOx fund, similar to the current Norwegian NOx fund, in the inland shipping market in Europe causes the availability of €13.7 million annually for the inland shipping sector to move to LNG. Assuming that all available money will be used, it is expected that vessels annually will move to LNG as fuel. This results into gas fuelled inland waterway vessels in the upcoming 10 years.

The third scenario is defined by a price advantage of using LNG as fuel, compared to LSMGO, in order of - and per m³ LSMGO equivalent. In this scenario, LNG suppliers are willing to secure shipping companies for favourable fuel prices. The LNG fuel supply chain is extensive, hence flexibility for shipping companies. Besides, Corporate Social Responsibility is an extra incentive for shipping companies to obtain charter contracts. At a price advantage level of and strong willing to pay for the view of Corporate Social Responsibility (CSR), it is expected that vessels will move to use LNG as fuel. At a price advantage level of .-, the business case starts for more vessels. From this, it can be expected that vessels will move to LNG as fuel.

For all scenarios, threat for the acceleration and potential economic profitability of using LNG as fuel for inland waterway vessels. Licensing LNG fuelled inland waterway vessels is conducted by the CCNR .

Concerns push vessels; it is difficult to determine if they will move to LNG as fuel, due limited operators and high operational requirements.

No scenario will predict a major breakthrough in using LNG as fuel for inland waterway vessels. The typical low fuel consumption of inland waterway vessels makes it difficult to have profitable investments on fuel efficient measures by inland waterway vessels, anyway. Cryonorm can serve, in an autonomous development, subsidized customers or customers who have another interest, such as launching customers or actors who are involved in the LNG supply chain.

If movers have an incentive by the potential of fuel costs savings, more customers can be expected by a lowered LNG fuel system price

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1. INTRODUCTION

Natural Gas (NG) can be used as fuel for several forms of transport. NG converted into liquid is called Liquefied Natural Gas (LNG). LNG has a favourable energy density for ease of transport and storage. On the other hand, LNG is cryogenic at -162 °C.

To use LNG as fuel, it is required to use an LNG fuel system. An LNG fuel system consists mainly of a cryogenic tank, for storage, and a regasification unit to convert LNG to NG. Cryonorm Systems B.V. is a designer and supplier of such LNG fuel systems for several forms of transport. In addition to this LNG fuel system, another type of engine is required.

Cryonorm already designed and supplied four inland waterway (IWW) vessels with a marine LNG fuel system. LNG as fuel was introduced by seagoing vessels, though there is also a propensity to move to LNG as fuel for IWW vessels. LNG as fuel for IWW vessels is the subject of investigation in this thesis, with the aim to define the business opportunities of LNG fuel systems for IWW vessels in different scenarios for Cryonorm.

In this research, the financial viability of LNG as fuel for inland waterway vessels is investigated. The financial viability depends mainly on fuel consumption, fuel prices and the required financial resources to move to LNG as fuel. With this investigation, the necessary preconditions in which shipping companies possibly will move to LNG as fuel are determined. These preconditions consist of the financial eligibility of inland waterway vessels and the extent to which obstacles, such as LNG bunkering logistics, have to be overcome. With this determination, scenarios are developed in which the business opportunities of LNG fuel systems for inland waterway vessels for Cryonorm are rendered for the next 10 years.

In this chapter, the problem description of LNG as fuel for IWW vessels is presented. Clear understanding of this problem description is needed. Subsequently, the research subject, research goal and the research questions are defined. At last, the research approach and scope of research is discussed.

1.1 Problem description

The problem description is determined, by a preliminary research on LNG as fuel for transport modalities and the inland shipping market, to substantiate findings in continuation of this thesis. With the problem description the research question and boundaries are determined to define business opportunities in scenarios of LNG fuel systems for IWW vessels for Cryonorm.

1.1.1 Inland shipping in Europe

In Europe, cargo transport by inland shipping is important as hinterland connection for sea ports, especially from North Sea ports connected by the Rhine. The Rhine is the main inland waterway hinterland connection of the port of Rotterdam to Germany and beyond. Inland shipping over the Rhine, which is responsible for 70% (Efin-group, 2004) of all transported goods by inland waterways in Europe, the main segments are dry bulk shipping, container shipping and tankers. (ABN, 2013) Transport by inland waterways has advantages on energy efficiency, costs (Hekkenberg, 2014) and environment (NEA & Panteia, 2010) compared to other forms of transport.

1.1.2 LNG as transport fuel

LNG as fuel for several forms of transport is used more and more. LNG as fuel has an environmental driver, fewer emissions (NEA & Panteia, 2010) on NOx, SOx and PM_{10} compared to diesels, but the economic potential is a key incentive for companies to move to LNG as fuel. (Sund; Whitefield, 2014) In this subparagraph, LNG as fuel for transport modalities is investigated.

LNG as fuel for Trucks

Logistics service provider Simon Loos has LNG-fuelled trucks to meet the need of Albert Heijn to have a cleaner and quieter transport in Amsterdam. (Loos, 2015) Besides cleaner transport, which contributes to Albert Heijns Corporate Social Responsibility (CSR), this quieter transport ensures Albert Heijn to supply their supermarkets earlier in the morning or later at night, due to noise restrictions mandated by the municipality of Amsterdam. Subsequently, the price advantage of LNG compared to diesel fluctuated between 30% and 43% last year. The main reason behind this price advantage is the lower VAT tax on LNG compared to diesel. See also Appendix A.

LNG as fuel for seagoing vessels

LNG as fuel for seagoing ships is a proven safe and commercially available solution to meet certain stringent emissions requirements and lower operating costs. (DNV-GL, 2014) By April 2015, more than 50 LNG-fuelled ships are in operation worldwide. (DNV-GL, 2014) Stringent emission regulations in Environmental Controlled Areas (ECA), both sulphur controlled area's (SECA) and future ECA's in Europe and North America, are administered by MARPOL of the International Maritime Organisation (IMO). In these (S)ECA's the emissions of NOx, SOx and PM_{10} are regulated. Introduction of these regulations was a motivation for some shipping companies to move to LNG as fuel (DNV-GL, 2014), which was possibly strengthened by fear of increasing oil prices.

Besides the international (S)ECA policy, there is another environmental policy operative in Norway, the Norwegian NOx fund. This NOx fund has the aim to make vessels cleaner by funding technological solutions, which make shipping cleaner and more sustainable. This fund is financed by international shipping companies, who visit Norwegian Ports with their vessels, and the Norwegian government. The NOx fund covers 80% of the initial costs to use gas as fuel and the port tariffs are lowered. (Johnsen, 2013)

LNG as fuel for inland waterway vessels

Systems to use LNG as fuel between seagoing- and IWW vessels have great similarity, and therewith investment costs for LNG systems. (Cryonorm, 2015) The initial cost to move to LNG as fuel for vessels consists mainly out of a new engine(s) and an LNG fuel system(s), both systems together is considered an LNG system in this study. Depending on the requirements the extra investment varies between

for IWW vessels, currently. (Cryonorm, 2015) Though, the structure and order of size of the total costs of shipping differs completely between seagoing- and IWW vessels. A striking different is the share of fuel costs on the total costs of shipping; for seagoing vessels it is 58% - 78% (Blikom, 2011) and for a typical Large Rhine Vessel 14% (Beelen, 2011), which is a commonly used large sized IWW vessel. Fuel consumption of inland vessels is typically quite low (MoVe IT!, 2014), compared to seagoing vessels, therefore the potential benefits are much less. (MoVe IT!, 2014) Hence, a financial viable modernization option to reduce fuel costs is difficult. Nonetheless, LNG as fuel is considered as one of the most potential retrofit solutions, with the aim to make the current fleet cleaner.

1.1.3 Emission regulations for inland shipping

For inland shipping there are limited emissions regulations applicable at this moment. These limited regulations consist out of the use of Low Sulphur Marine Gas Oil (LSMGO) (EVO a. , 2011) and new engines have to meet an emission regulation, which is outdated compared to regulations for truck engines. (Hekkenberg, 2014) Moreover, it is unclear which and when new stringent emissions regulations are mandated for inland shipping in Europe. (Tachi, 2015) If new stringent emissions regulations are regulated on emission of NOx, SOx and PM_{10}, LNG as fuel could be a solution. (TNO, et al., 2011) On the other hand if new emission regulations have to meet more than just abatement of NOx, SOx and PM_{10} emissions, it is unclear how other emissions, , of LNG as fuel for IWW effects the environment, .

1.1.4 IWW shipping companies

Inland shipping companies and owners are always seeking to make profit out of transport. Strong competition and overcapacity in this market has resulted in low freight margins these days (ABN, 2013), hence inland shipping companies can improve their profits by only cost reductions, service improvement or accessing niche markets. (Hekkenberg dr. ir. , 2013)

Cost reduction can be achieved by lower fuel costs and service improvement by contribution to a customer's Corporate Social Responsibility (CSR) or an environmental sustainable image. Although, to what extent they can improve their profits is currently unknown. On the other hand, inland shipping market circumstances are acute and loans are currently difficult to obtain. (Schillemans, 2015) Loan payments of such LNG system shall become a large share of the total costs of shipping for IWW companies.

1.1.5 Supply chain of LNG

Natural gas is an important source of energy in Europe, especially in the Netherlands, since the discovery of gas fields. Gas solutions can contribute to meet the emissions requirements by the European Union. (TKI-Gas, 2015) Part of these gas solutions are imports of LNG from overseas to Europe, by using LNG terminals. Besides, these LNG terminals will contribute to lower gas prices and strategic diversification of gas supplies in Europe. (Gas-unie, 2015)

LNG import to LNG terminals in Europe, such as the Gate Terminal on the Maasvlakte, is called the large scale LNG market. Developments in the large scale LNG supply chain caused innovations for small scale LNG use, like LNG as fuel for IWW vessels. Although, the supply chain of LNG, both large and small scale, is currently under construction in Europe, and is still in its deadlock.

This term deadlock is formulated, by DNV-GL, as follows:
"Lack of appropriate infrastructure, such as bunkering facilities and supply chain, and uncertainty regarding long-term availability of fuel are additional barriers for the introduction of any new fuel. That is, owners will not start using new fuels if infrastructure is not available, and energy providers will not finance expensive infrastructure without first securing customers. Breaking this deadlock will require a coordinated, industry-wide effort and the political will to invest in the development of new infrastructure." (DNV-GL-AS, 2014, p. 9)

Within the LNG supply chain, involved companies are interdependent actors to each other and they have a shared economic interest to create successive LNG markets. (Cryovat R. v., 2015) Although there is yet no small scale LNG bunker facility operational to refuel LNG fuelled IWW vessels, bunkering LNG to IWW vessels is currently achieved by truck to ship transfer. The break bulk terminal on the Maasvlakte will be operational in the fourth quarter of 2016, where LNG can be bunkered directly from the terminal. Subsequently, satellite plants among the waterways will follow.

The supply chain of LNG as fuel for IWW vessels could be satisfactory, with this Break Bulk Terminal on the Maasvlakte. Partly because the constraint trading pattern of IWW vessels and oversized storage capacity of LNG at current LNG fuelled IWW vessels. (Cryonorm, 2015) An improved LNG supply chain can reduce the LNG price and improve flexibility by IWW shipping companies. This way, the technical requirements to meet the customers need can probably be changed in a positive way. With a smaller LNG fuel storage tank, the investment costs can be reduced.

1.1.6 LNG prices

In the Netherlands, several market players offer LNG for small scale use, for example: Primagaz, Linde Gas, TitanLNG and LNG24. The current LNG contracts and bunker prices offered vary and kept quiet. (Sund; Whitefield, 2014) (Slooff, 2015) LNG is bunkered by trucks for IWW vessels to date, also known as Truck to Ship (TTS). Pipeline/Terminal to Ship (PTS) can be expected operational by the break bulk terminal on the Maasvlakte next year, quarter four in 2016, and probably more inland terminal will follow in the coming years. (Boktor, 2015) (Hof, 2015) (LNG-platform)

Although LNG bunker prices are kept quiet, some market players offer retail prices. Currently, the difference between wholesale and retail prices is significant for LNG, which is opposite to oil based fuels. (Sund; Whitefield, 2014)

> "The price of LNG (bunkered in the ship) varies between . This price depends on the LNG market price and bunker location." (E.Buthker, p. 1)
>
> Primagaz offers LNG also by truck, by conveniently load, . (Slooff, 2015)
>
> Anthony Veder can bunker their vessels for LNG, July 2015. (Engelen, 2015) This is .

Conventional fuelled IWW vessels use Low Sulphur Marine Gas Oil (LSMGO) as fuel. The price of LSMGO is dependent on two factors, the price of LSMGO and the Dollar/Euro exchange rate. Figure 1 shows a graph in which the LNG bunker prices and LSMGO bunker prices are fitted to each other on Euro (€) per Mega Joule (MJ). The price difference of LNG compared to LSMGO, by the lowest known bunker price in the Netherlands, varies between - to last year, therefore the price difference can be considered as uncertain for the future. The prices of LNG were more stable.

It should be noted that seagoing vessels can also use Marine Diesel Oil (MDO), beside LSMGO in SECA's, the price of which only knows small fluctuations. The long term graph in Figure 1 shows that the price of gas oil fluctuated between €700.- per m^3 and €228.- per m^3 since 2005. IWW vessels are obliged to use LSMGO instead of gas oil since 1 January 2011, (Beelen, 2011) which has an extra price of approximately €20.- per m^3 LSMGO. (EVO-gasolieverbruik, 2011)

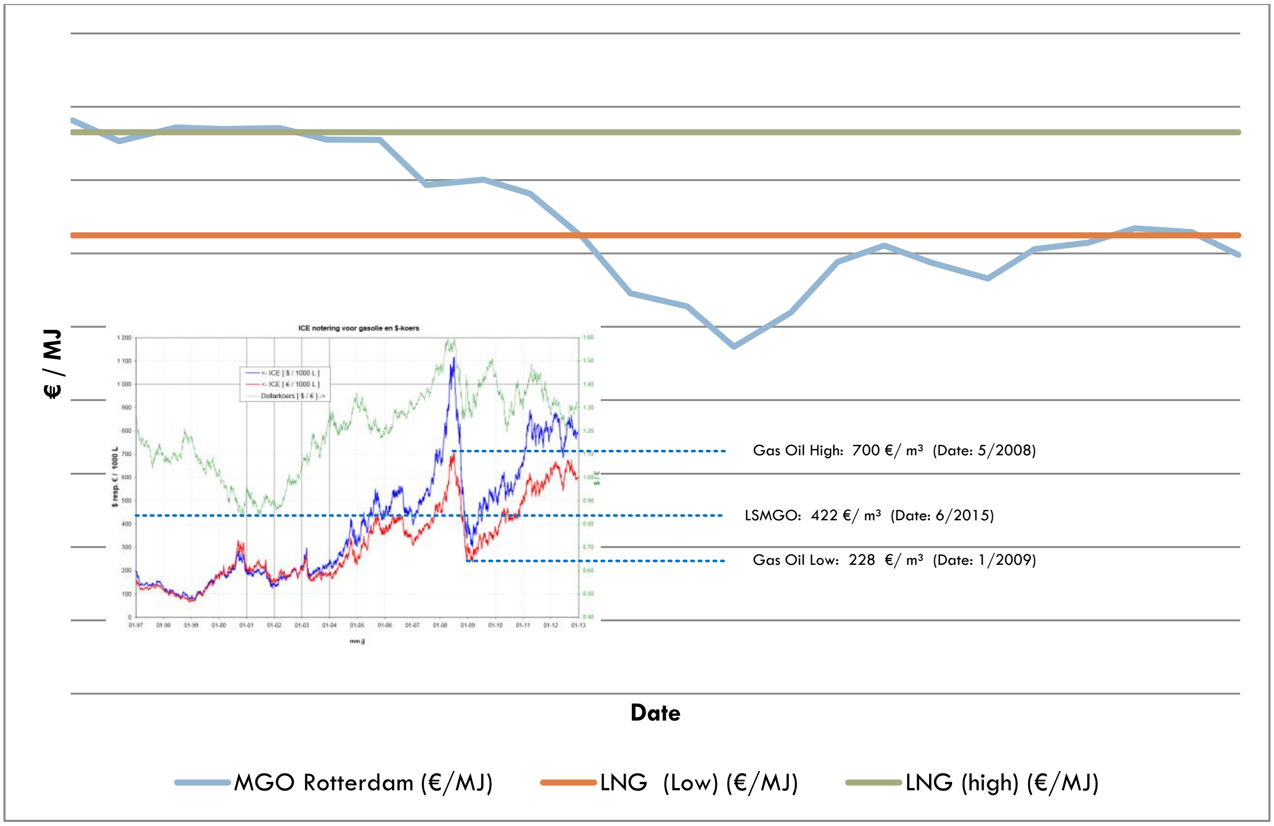

FIGURE 1: BUNKER PRICES LNG AND LSMGO. SOURCES: (SHIPANDBUNKER, 2015) (ECB, 2015) (BUTHKER) (E.BUTHKER, 2015) (SLOOFF, 2015) (OMMEREN B, 2013)

By August 20th, 2015, LSMGO was priced €331.- per m^3 (Shipandbunker, 2015), which is 0.0094 €/MJ (Buthker).

1.1.7 Preliminary conclusions of LNG as fuel for IWW vessels

In this subparagraph, conclusions are drawn from the preliminary research.

Inland shipping in Europe

- The Rhine is responsible for 70% of all transported goods by inland waterways in Europe.

LNG as fuel for transport modalities, inland shipping excluded

- LNG as fuel for trucks; VAT causes price advantages to use LNG as fuel and noise restrictions are an incentive for some companies to move.
- LNG as fuel for seagoing vessels; (S)ECA's were an incentive to move to LNG as fuel for shipping companies, probably strengthened by rising fuel prices.
- In Norway, the Norwegian NOx fund covers 80% of initial costs to move to LNG as fuel and port tariffs are lowered.

LNG as fuel for inland waterway vessels

- The success stories of LNG as fuel for other transport modes have probably caused the propensity to use LNG as fuel for IWW vessels. Though, no other incentive than temporary subsidies for IWW vessels to move to LNG as fuel are available.
- The future emission regulations for inland shipping are unclear and uncertain for the future.

LNG has emission advantages on NOx, SOx and PM.

- It is difficult to have viable investments on fuel efficient measures by IWW vessels. (MoVe IT!, 2014)
- LNG as fuel is considered as one of the potential retrofit solutions.

Inland shipping market

- Inland shipping market is acute with low freight margins.
- Loans for investments are difficult to obtain.
- Share of fuel cost in total costs of shipping for IWW vessels is low compared to seagoing vessels.

Supply chain of LNG and LNG systems

- The supply of LNG for LNG fuelled IWW vessels is currently satisfactory for navigation over the Rhine. Though, the Break Bulk Terminal, and probably others, improves the supply chain in favor for LNG as fuel for inland waterway vessels.
- Bunker stations in Europe will improve flexibility for IWW shipping companies and probably change technical requirements to LNG systems of IWW vessels.
- Current LNG fuelled IWW vessels are equipped with large LNG storage tanks.

LNG prices

- Current offered LNG contracts and bunker prices are varied and kept quiet.
- Difference between wholesale and retail prices are significant for LNG, which is opposite to oil based fuels.
- Price advantage of LNG, by the lowest known LNG price, compared to LSMGO varies between - past year and is therefore uncertain for the future.

1.2 Research subject and goal

LNG as fuel for IWW vessels is the subject of investigation in this thesis. The aim of this research is to define business opportunities in different scenarios of LNG fuel systems for LNG fuelled IWW vessels for Cryonorm. The business opportunities should eventually be mentioned into the business model of LNG fuel systems for IWW vessels of Cryonorm.

Cryonorm already equipped four IWW vessels with one or more LNG fuel systems. The owners of these vessels were probably driven by innovation, environmental green image and expected lower fuel costs, but in all probability a subsidy was the key incentive to overcome the initial investment of the LNG system.

Cryonorm believes that LNG as fuel is the fuel solution for inland waterway vessels. Currently, Cryonorm is leading designer and supplier for such LNG fuel systems.

1.3 Research questions and approach

According to the problem description and research goal, the main research question is defined:

What are the business opportunities, in different scenarios, of LNG marine fuel systems for inland waterway vessels for Cryonorm?

The main research question is broken down into less complex subquestions. These subquestions lead to a better understanding of the research subject. Finally, answers of these subquestions provide all necessary information to answer the main research question.

Sub question 1:

Which vessels can Cryonorm serve with LNG fuel systems and to what extent are cost items of the total costs of shipping changed?

Answering this subquestion gives insight in the developments and possibilities of LNG systems for inland waterway vessels. This way, the market segments for LNG fuel systems will be determined. Subsequently, the total costs of shipping can be separated into different cost items, both fixed and variable. This subquestion must clarify which cost items are affected by using LNG as fuel. These cost items are essential to determine the potential profitability of LNG as fuel for shipping companies. Some cost items can be determined quantitative, with certainty, others have to be estimated. The cost items related to LNG as fuel will be gathered by literature research and interviews with experts in the field. These costs items will be used as parameters in the business case analysis.

Sub question 2:

What are the preconditions, both fuel prices and fuel consumption, in which it is economical profitable for shipping companies to move to LNG as fuel?

A tool, to do the business case analysis, will be developed in which the price difference of LNG – LSMGO, which is uncertain, is set against the fuel consumption, cost items and investment. With this tool it can be determined when LNG as fuel is economically profitable for different types and sizes of vessels.

Sub question 3:

What are the obstacles and opportunities for LNG as fuel for inland waterway vessels in Europe?

With a view to be able to consider LNG as a ready fuel solution for inland waterway vessels, some obstacles will have to be overcome. In this section, the current obstacles and opportunities for shipping companies to move to LNG as fuel is investigated. With this information, developments and trends are made clear, in order to define possible scenarios of LNG as fuel.

A framework of 6 aspects, based on Shell's scenario approaches (Shell, 2013), will be used to include all important aspects. The aim of this framework is that plausible scenarios can be developed and implications can easily be qualified.

Sub question 4:

Which market segments will be eligible to move to LNG as fuel in different scenarios, and to what extent can this be expected?

First, scenarios in which the use of LNG as fuel is increased are developed and the implications out of this are qualified. With these scenarios the most eligible market segments can be determined. By using the business case tool and the implications out the scenarios a fleet projection can be carried out. Answering this question will facilitate to estimate the market size for Cryonorm in different scenarios.

Research approach and thesis outline

This part shows a representation of the research approach successively to the subquestions. This research approach has the aim to ensure consistency and control of arising boundaries in continuation of this investigation. (Leeuw, 1996)

A schematic representation of the research approach is shown in Figure 2. The problem description is the starting point of this study. Hence, clear understanding is needful. With this problem description, the research subject, research goal, research questions and scope of research are defined in chapter 1.

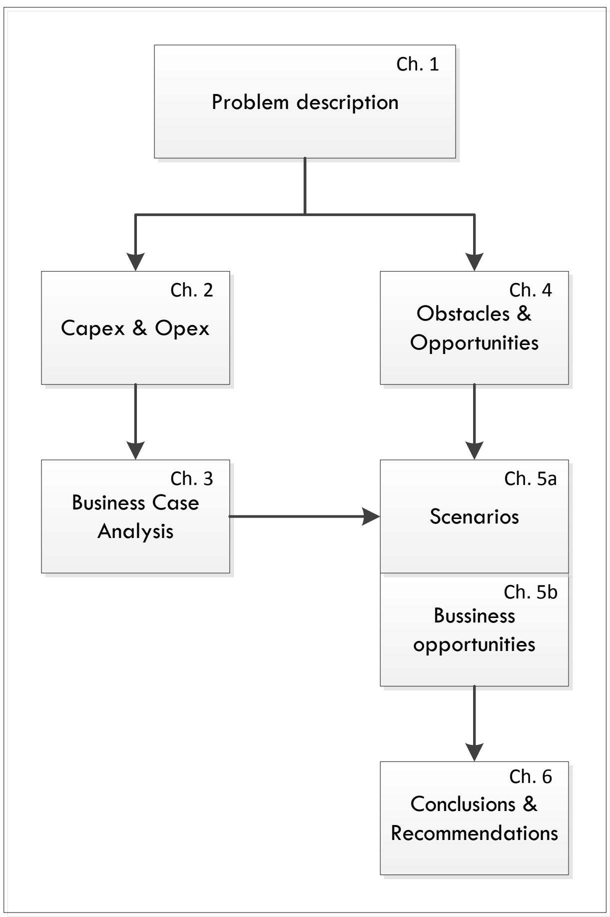

FIGURE 2: RESEARCH APPROACH

Investments to use LNG as fuel will inevitably change the cost items of a vessel. In chapter 2, the cost items affected by LNG as fuel are investigated to eventually determine the potential financial profitability of this fuel in chapter 3.

To be able to consider LNG as a ready fuel solution for IWW vessels, some obstacles will have to be overcome. These obstacles and opportunities will be investigated in chapter 4. With this information, developments and trends are made clear in order to define scenarios and its implications out of it of LNG as fuel. These scenarios will be used to define the most eligible market segments. This way, the business opportunities for Cryonorm, in different scenarios, of LNG fuel systems for inland waterway vessels can be determined. In chapter 6, the conclusions and recommendations out of this research will be presented and the scenarios will be discussed.

1.4 Scope of research

The scope of research is described in this paragraph, which corresponds with the problem description, research goal and research approach. The scope of research has also the aim to ensure consistency and control of arising research boundaries in this study. (Leeuw, 1996)

This investigation is limited to inland shipping over the Rhine, due a limited LNG supply chain and the large share of total transport over this inland waterways. Besides, Cryonorm is a small company and their knowledge and familiarity is focused on the European market.

Because Cryonorm believes that LNG is the fuel solution of the future, the main market segments and vessels sizes are considered. This way, just tankers, dry-bulk and container vessels are taken into account. It is expected that the financial profitability of using LNG as fuel is dependent, among other things, on the fuel consumption. Therefore, this research will be limited to inland waterway vessels with favourable fuel consumption. Hence, a CEMT Class IV and greater, including Koppelverbanden and push convoys, with a width of at least 11.4 meters, are taken into account. By means of the uncertainty concerning future fuel prices and availability, only dual fuel engine configurations are considered in the business case analysis, since this configuration has the most favourable price.

To determine the economical profitability of using LNG as fuel, the best case situation will be considered. This way, the most favourable operating profiles of inland waterway vessels are considered. From this best case situation, possible scenarios are developed, in which LNG as fuel is increasingly used, according to a framework, based on the Shell's scenario's approach, with six facets on the obstacles and opportunities to consider LNG as a ready fuel. These six aspects will be taken into account to ensure consistency and comprehensivity for the scenarios. These aspects are; environment, economy, finance, Corporate Social Responsibility (CSR), technology and politics.

2 CAPITAL AND OPERATIONAL EXPENDITURES OF LNG AS FUEL

Using LNG as fuel will inevitable change the cost items of a vessel. In this chapter, the cost items affected by LNG as fuel are investigated to eventually conduct a business case analysis in chapter 3.

The main cost items of shipping are determined in literature (Beelen, 2011), whereby distinction can be made on:

- **Capital costs**
- **Costs of repair and maintenance**
- **Fuel costs**
- Labour cost
- Insurance cost
- Overhead cost
- Other costs

It is assumed that the use of LNG as fuel will alter mainly three costs items, presented in bold. Per cost item the change in costs of LNG as fuel is investigated. Capital costs are capital expenditures and fuel costs are operational expenditures. On the other hand, costs of repair and maintenance can be both.

The emphasis in this research is on the potential of using LNG as fuel as profitable commercial alternative for inland waterway vessels. Estimation of the cost items is conducted from a best case perspective. This means, using favourable parameters to determine the cost items in favour of using LNG as fuel. In this study, this is called the ‘as good as it gets’ approach. Eventually, these ‘as good as it gets’ values of parameters will be compared using literature data. Hence, the break-even points for the business cases can be determined by literature parameters and the best case situation.

As noted in the problem description, fuel prices are uncertain and there are low freight margins, hence higher fuel costs of shipping are undesirable. Unfavourable price of LNG causes a necessity to have fuel security, by means of that, a dual fuel engine, runs both low sulphur marine gas oil (LSMGO) and LNG, for IWW vessels is assumed as best option. Moreover, this type of LNG systems configuration is the cheapest and is therefore in continuity with this approach.

2.1 Costs of fuel consumption

The change in costs of fuel consumption depends on the fuel prices, both LSMGO and LNG in this case, and the vessels fuel consumption. As noted in the problem description, fuel prices are uncertain, for this reason the potential of fuel prices is investigated. This determines together with the fuel consumption the potential fuel costs savings.

2.1.1 Fuel prices

This paragraph must be read in conjunction with the findings out of the preliminary research in subparagraph 1.1.6. Appendix a shows a deeper study on the LNG price, but the main findings out of this study are presented in this paragraph.

In this section, the economic potential of LNG as fuel for inland waterway vessels is analysed. With this information a reference value of the maximum economic potential will be defined in this paragraph. This maximum economic potential is in continuity of the ‘as good as it gets’ approach and defines the potential price advantage between the fuels.

Figure 3 shows the price development of LSMGO and the economic potential of LNG as fuel, past year.

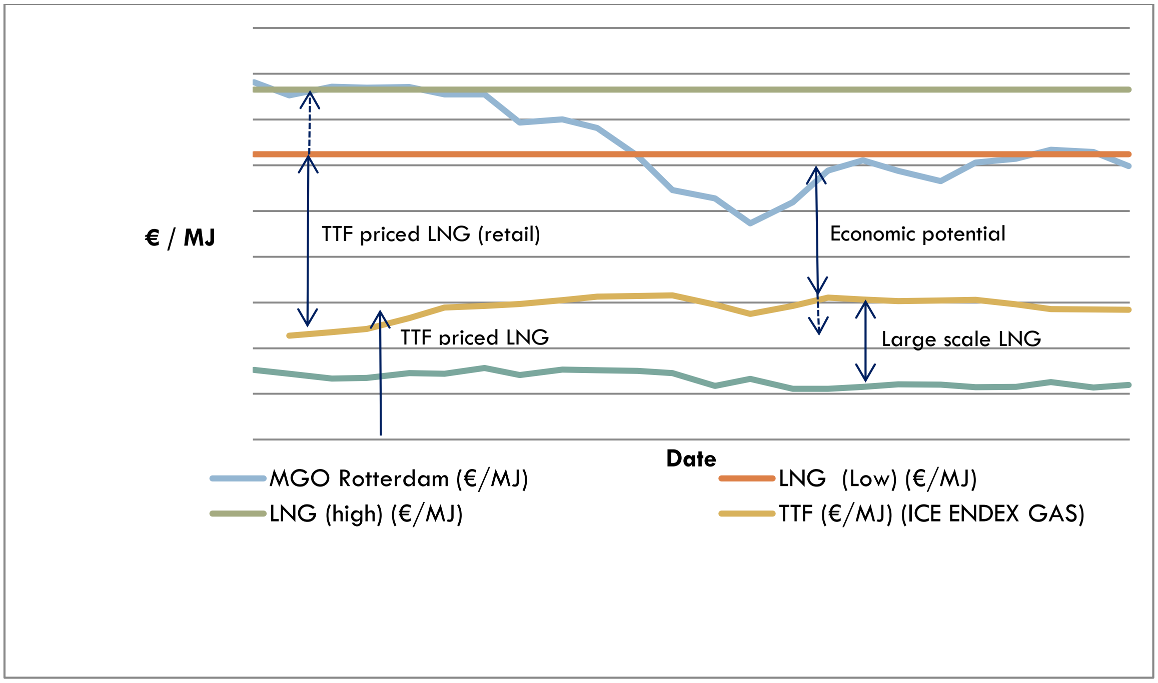

FIGURE 3: ECONOMIC POTENTIAL OF LNG AS FUEL. OWN COMPOSITION. SOURCES: (SHIPANDBUNKER, 2015) (OMMEREN B, 2013) (BUTHKER) (EVO-GASOLIEVERBRUIK, 2011) (TTFGAS, 2014-2015)

Current developments of the LNG supply chain could cause a LNG wholesale price at a level of the Title Transfer Facility (TTF) price, which represents the gas market price in the Netherlands. The price difference between LSMGO and TTF gas price can be seen as the economic potential, though retail trade takes in a part of this economic potential.

Hence, developments in the LNG supply chain will cause a reduction between these prices, which is in context with the definition of deadlock. In addition, all fuel prices are dependent on the Dollar/Euro rate, especially LSMGO.

Figure 3 shows an economic potential of approximately €/MJ, equivalent to a discount of € per m^3 LSMGO. This economic potential, together with a favorable price differences, is the key incentive for shipping companies to move to LNG. (Sund; Whitefield, 2014) Because of this, it is expected that there is causality between the fuel prices and strength of an incentive for shipping companies to move to LNG as fuel.

Hence, continuous monitoring the fuel price developments, as in Figure 3, is recommended, to determine the market development for LNG fuel systems for IWW vessels. Besides, it can be expected that production of gas to liquids (GTL), by a Fischer-Tropsch process, will eventually reduce the maximum economic potential of LNG at high LSMGO prices.

The assumed economic potential of will be used as reference value in the business case analysis. This reference value is part of the 'as good as it can get' approach.

2.1.2 Fuel consumption

Potential for fuel costs savings depends on two aspects, price difference between fuels and fuel consumption. In this subparagraph, fuel consumption is investigated per vessels size. First, literature data of fuel consumption per vessels size is gathered. Secondly, the required fuel for a roundtrip, Rotterdam – Koblenz, is calculated, likewise to determine the minimum requirements of the LNG fuel system. At last, the highest conceivable fuel consumption per vessels size is calculated. Last two aspects are in continuation of the 'as good as it gets' approach. The range between these values will eventually be analysed and used in the business case analysis.

Literature data
Figure 5 shows the annual fuel consumptions per size of vessels defined out of literature data, which is studied in Appendix B. Concerns motor vessels, the annual fuel consumptions are in range of approximately 50 to 1100 m^3 LSMGO. Concerns, push vessels, literature data of the Veerhaven X shows an annual fuel consumption of approximately 3400 m^3 LSMGO. Though, there are a limited number of push convoys and this specific push vessel was 87% of the time sailing with six lighters. It can therefore be expected that there is no inland waterway vessels which consumes significant more than 3500 m^3 LSMGO. See also, Appendix B: vessels and their fuel consumption.

Roundtrip fuel consumption
Appendix B: vessels and their fuel consumption, show an extensive study on the fuel consumption for a roundtrip Rotterdam to Koblenz. The roundtrip fuel consumptions are estimated by rule of thumb values out of literature. Subsequently, the operational profiles are assumed and an annual fuel consumption per vessel size is determined, see Figure 5. For this calculation intensive operational parameters are used, which could be representative in some cases for operators. In addition, the fuel consumption per vessels size on the considered trading pattern helps to determine the minimum requirements of the LNG fuel system. Out of an analysis of the calculated annual fuel consumption is concluded that these values are uncertain, though they can be used as an indication.

Highest conceivable fuel consumption
The calculated annual fuel consumption by roundtrips is uncertain. Hence, the highest conceivable fuel usage will be calculated per vessels size. This will be in continuation of the 'as good as it can get' approach. In contrast to seagoing vessels, inland waterway vessels are often more subjected to water flows, limited draft, etc., therefore they often sail with limited engine power. A performance measurement of the Veerhaven X (Godjevac; Meij, 2014) is used to determine highest conceivable annual fuel consumption for other vessels, since the Veerhaven X is operated continuous with six barges, also called lighters, and has favourable port waiting times.

Figure 4, firstly, shows the power used in the operational profile of the Veerhaven X. This graph is a copy and published by the Delft University of Delft. (Godjevac; Meij, 2014) Subsequently, the operational profile and general assumptions for this calculation are presented in the figure. By using these operational parameters and the specific installed engine power per vessel size (Vesseldatabase, 2015), the annual fuel consumption for each motor vessels is determined, see Figure 5 by 'as good as it can get' values. These values are not representative for the fleet, but in continuation of the 'as good as it can get' approach, it could probably give more certain conclusions. Moreover, this quantity could hypothetically be representative for a very few motor vessels.

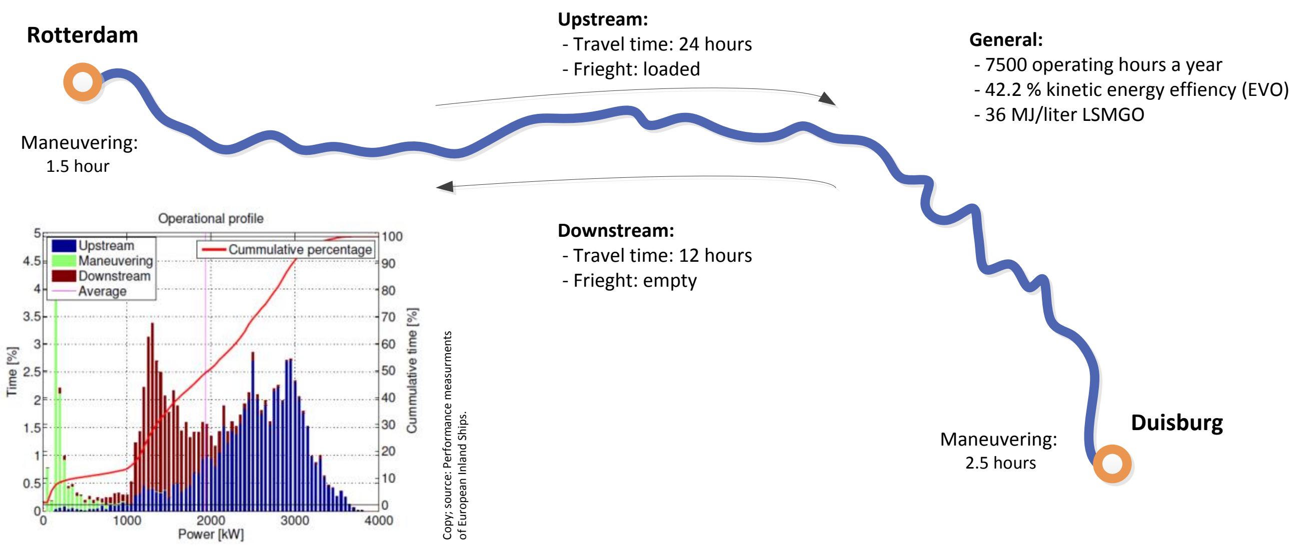

FIGURE 4: OPERATIONAL PROFILE AND CONDITIONS OF HIGHEST CONCEIVABLE FUEL CONSUMPTION. OWN COMPOSITION: (WARTSILA B. , 2013) (GODJEVAC; MEIJ, 2014) (EVO-GASOLIEVERBRUIK, 2011)

2.1.3 Influencing factors on fuel consumption

The quantity fuel used is heavily dependent on operational parameters and therefore productivity, such as port waiting times, operational employability and trading pattern. In the study of the annual fuel consumption, see Figure 5 and Appendix B, the operational parameters are included. From a performed sensitivity analysis the difference between calculated and out of literature found data can be explained by different types of ownership and the market they serve. Subsequently, push convoys have great advantage on port waiting times, by loading and unloading, due their flexibility. Using the push convoys' flexibility for motor vessels results into very high annual fuel consumptions, which is favourable for the business case of using LNG as fuel, though it is not representative for main part of the motor vessel fleet. On the other hand, type of ownership can cause a major difference, see next section.

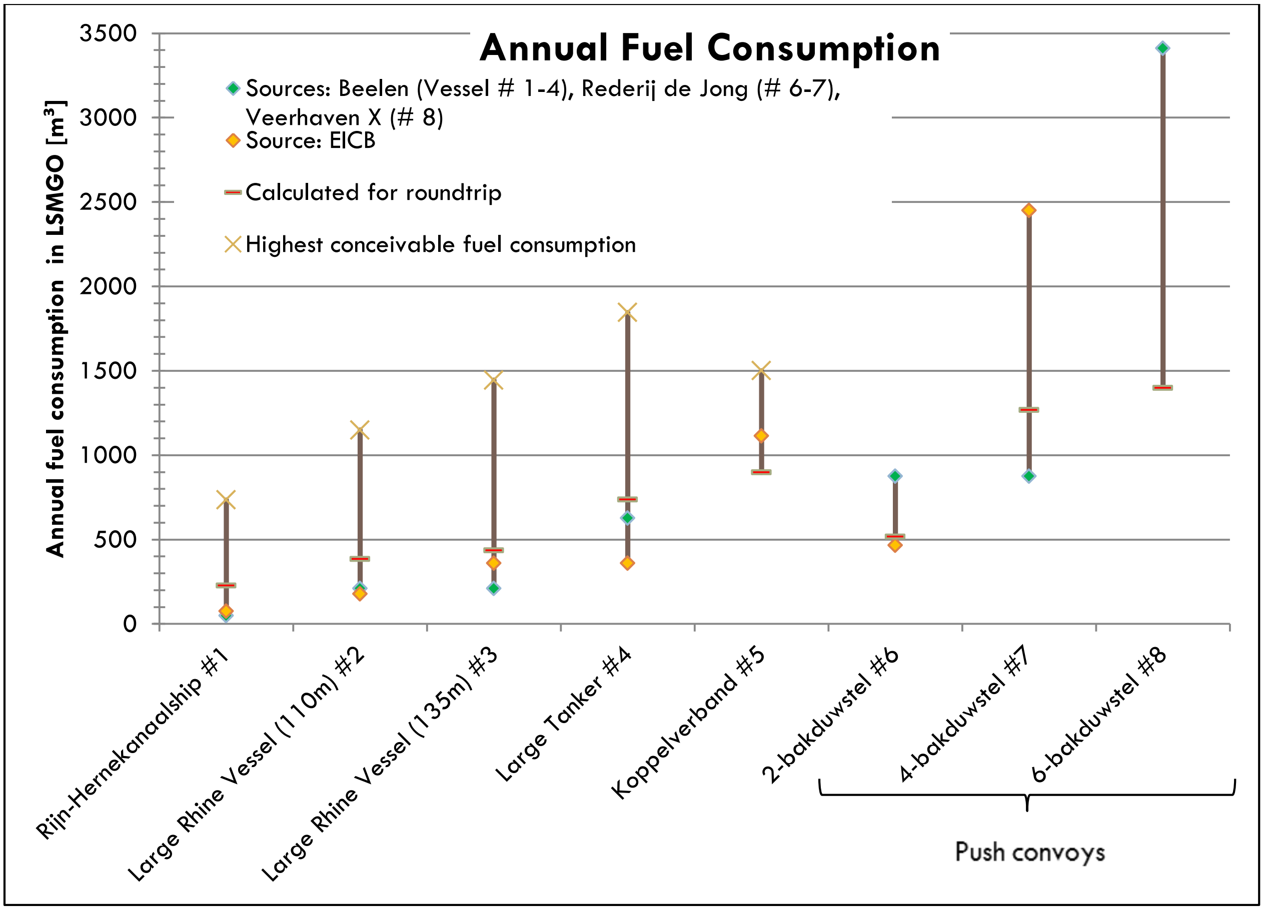

FIGURE 5: ANNUAL FUEL CONSUMPTION VESSELS. OWN COMPOSITION, SOURCES: (BEELEN, 2011) (VIA-DONAU, 2007) (EICB P. I., 2015) (EVO & OMMEREN, >2011) (E.BUTHKER, 2015) (GODJEVAC; MEIJ, 2014) (VESSELDATABASE, 2015)

Owner-operators

The motor vessels, Rijn-Hernekanaalship and Large Rhine Vessel (110m), are predominately owned by owners-operators and often serve the sport market. The difference between serving the spot market or in a time charter can drastically change parameters, such as fuel consumption, by approximately by 60%. (Beelen, 2011)

It can be concluded that the calculated annual fuel consumption values for the vessels, Rijn-Hernekanaalship and Large Rhine Vessel (110m), are representative for a smaller part of the fleet, which probably serve the charter market. On the other hand, vessels with the highest conceivable fuel consumption are supposedly rare.

Shipping companies

Motor vessels, CEMT Vb and higher, are predominately owned by shipping companies, who often serve the charter market. Because of this, it is expected that the annual fuel calculations are representative for a larger part of the fleet of the considered motor vessels, even higher values can be expected.

Larger push convoys are operated continuous (Beelen, 2011), besides, they can have great flexibility on (un)loading times (Wartsila b. , 2013), therefore their fuel consumption can be expected higher, though fleet size is very small.

2.2 Capital expenditures of LNG as fuel

In this paragraph, the capital expenditures involved to move to LNG as fuel are presented. There are mainly three costs aspects to move to LNG as fuel, either retrofit or newly built. These cost aspects together are the initial investments for a vessels owner to move to LNG as fuel.

Cost aspects of investment:

- LNG fuel system costs
- Dual fuel engine costs
- Yard costs

Training costs of employees and income losses due conversion time are outlined in this study. The costs for LNG fuel systems and dual fuel engines are estimated with certainty. On the other hand, yard costs are estimated by interviews with experts in the field, for this reason they carry some uncertainty.

2.2.1 Costs of LNG fuel system

Figure 6 shows a cost breakdown structure of a LNG fuel system, applicable for inland waterway vessels, offered by Cryonorm in terms of a quotation. For this cost breakdown 44 quotations were analyzed, whereby 26 quotations were complete and comparable. Distinction is made between one or two LNG fuel systems, which are required for other type of propulsion.

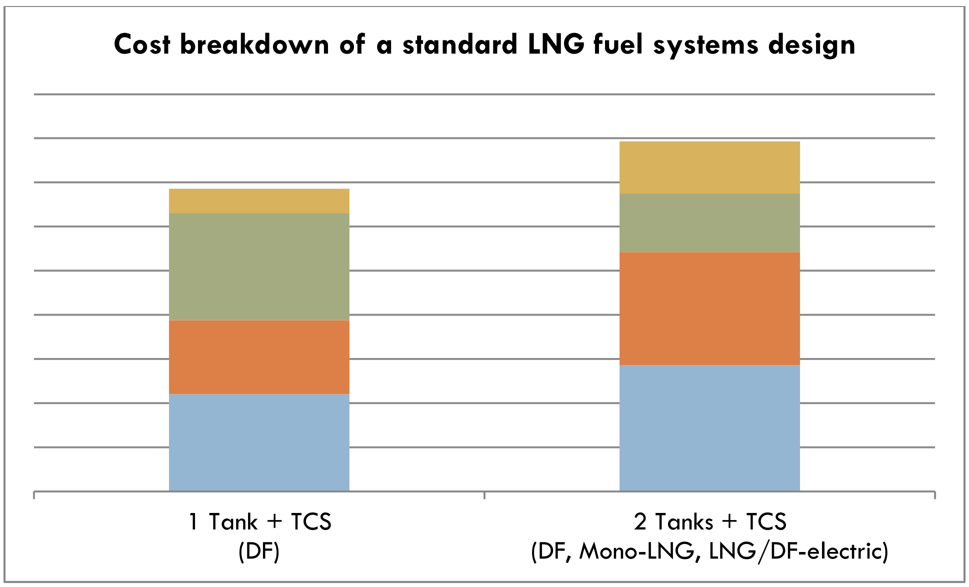

FIGURE 6: COST BREAKDOWN OF LNG FUEL SYSTEMS. OWN COMPOSTION, BASED ON 26 QUOTATIONS OF CRYONORM

The tank connection space (TCS), apart from the tank, consists out of equipment to process LNG into NG. Labor consists out of engineering, manufacturing and onside placement of the LNG fuel system. The cost item: others consist mainly out of transport expenses and certification by class societies.

Within the cost breakdown, the costs of bunker stations, normally two installed, heating glycol system and process control system are excluded.

Prices of excluded cost items:

- Bunker station: € .- each
- Heating glycol system: € .-
- Process control system: € .-

The average offered quotations of a single LNG fuel system for inland waterway vessels offered by Cryonorm is approximately € .-, Appendix C, presents a study on the price of LNG fuel systems. In addition, the best price of LNG fuel systems is herein determined.

Best price of LNG fuel systems

Figure 6 shows the cost breakdown structure of LNG fuel systems. The LNG storage tank is supplied to Cryonorm and is for % responsible for the total price of a single LNG fuel system on average. Appendix C shows that smaller sized LNG storage tanks can easily lower the total costs of an LNG fuel system by € . Moreover, tank and labour costs can drastically be reduced by large number of orders. It is expected that a simple design and a large order quantity can reduce the total costs of an LNG fuel system to € , for a motor vessel with a length of ≤110m. It is expected that this best price become more expensive over time, due stringent safety regulations, see Appendix C.

2.2.2 Engine costs

In this paragraph, the engine costs, which are one of the three initial investment cost aspects to move to LNG as fuel, are presented, with the emphasis on dual fuel engines. These engine costs are estimated by interviews and quotations of engine manufactures or resellers.

Each engine requires a gas valve unit (GVU). The price for such GVU is approximately .- (Bolier A. v., 2015) to € for each engine. (Cryonorm, 2015) (Wartsila.a, 2013)

The smallest available dual fuelled engines for IWW vessels, which are commonly used as engine-generator for larger seagoing vessels, have a maximum engine rating of approximately 1050 kWh. Large Rhine Vessels (110m) can be equipped with a single engine. Larger vessels commonly use multiple engines, sometimes with more power each.

These type of engines have a price of approximately € , for a Caterpillar (Bolier A. v., 2015), and € .- for a Wartsila engine. (Bolier, 2015)(Cryonorm, 2015)

Dual fuel engines are approximately 20% larger in size, as well as the combustion volume, to gain the same amount of engine power, based on continuous service ratings. Beside the costs of a GVU, dual fuel engines are approximately % more expensive than LSMGO fuelled engines, mainly due control systems, ceramic materials and additional components. (Bolier A. v., 2015)

The additional charge for fully installed dual fuel engine, both engine and GVU, can therefore be estimated between € .- and € ,-.

2.2.3 Yard costs

The yard costs are dependent whether it is a newly built vessel or the LNG system is retrofitted. In the most standard LNG fuel systems configuration, for new built dual fuel LRV (110m), the yard costs are approximately € .-, based on two quotations (Glorie J. , 2015) and experts (Wetering Rotterdam, 2015). The yard costs consist mainly out of LNG fuel tank socket, venting systems, interconnection piping and safety alarm systems. The costs can easily vary for different LNG fuel system configurations, hence the presented price level can be considered as favourable.

2.2.4 Influencing factors on capital expenditures

The required initial investment costs are based on a standard design, usually only achievable by newly built dry bulk or tanker vessel. Pointed out, by investigation in Appendix C, are factors that can influence the initial investment in a negative way, these are:

- Size of Vessel (class).
- Type of vessel (dry-bulk, container or tanker).
- Number of engine(s).
- Propulsion system, in this case dual fuel engine(s).
- Required maximum power.
- Place of LNG storage tank.
- Size of LNG storage tank.
- Retrofit or newly built.

2.2.5 Total costs to move to LNG as fuel

In this paragraph, the additional required additional investment costs to move to LNG as fuel are presented, per type of vessel, by application of the data out of the previous subparagraphs. The first price level is based on a very simple design in a situation with large orders, hence it can be expected that this is the lowest conceivable price to move to LNG as fuel. Subsequently, the other prices are based on current prices and therewithal, as third, with a special design, which is often required.

Rijn-Hernekanaalship and Large Rhine Vessel (110m)

For this configuration a motor vessel, class CEMT IV and Va, with one dual fuel engine is considered. In Table 1 the total cost to move to LNG as fuel is presented.

TABLE 1: TOTAL INVESTMENT COSTS FOR MOTOR VESSELS ≤110M.

Parameter	**Costs (€)**			
	Simple (ideal)	**Tanker (standard)**	**Container (special)**	***Comment:***
LNG fuel system				*With certainty*
TCS Tank [40 m³] Bunker station Heating glycol system Process control system Labour Others				**Vertical tank in front* **40 m³ has price advantage* **2 bunker stations* **Customized* **Customized*
Engine				*With certainty*
Dual fuel engine Discount engine () Gas valve unit				*Caterpillar/*Wartsila* *Normal LSMGO engine*
Yard				
Socket, venting, piping, alarms. Extra piping				 **Tank in front*
Sub total				

Potentially, in a best case situation, a simple design in favorable conditions can reduce the costs of an LNG fuel system by %. Moreover, the total costs of an LNG system can be reduced by %.

Large Rhine Vessel 135m (LRV 135m), Large Tanker (LT) and Koppelverband (KV),

For this case motor vessels, class CEMT Vb and VIb, Large Rhine Vessels (135m), Large Tankers and Koppelverbanden (KV), with two dual fuel engines and one LNG-fuel tank, are considered. A 60 m³ LNG fuel storage tanks is considered for the Large Tanker and container Koppelverbanden. Table 2 shows the total investment cost to move to LNG as fuel for the considered vessels.

TABLE 2: TOTAL INVESTMENT COSTS FOR LRV, LT AND KV

Parameter	**Costs (€)**				
	Simple (ideal)	**LRV and KV**	**Large Tanker**	**Container KV**	***Comment:***
LNG fuel system					*With certainty*
TCS Tank [40 m³] / [60m³]* Bunker station Heating glycol system Process control system Labour Others					
Engine					*With certainty*
Dual fuel engine Gas valve unit Discount engine ()					
Yard					
Socket, venting, piping, alarms. Extra piping					
Sub total					

Potentially, in a best case situation, a simple design in favorable conditions can reduce the costs of an LNG fuel system by %. Moreover, the total costs of an LNG system can be reduced by %.

Push vessels

In this section, the total initial investment cost to move to LNG as fuel for push vessels is calculated. Push vessels are designed for pushing lighters, unto 6 lighters on the Rhine. In this investigation, larger push vessels with barges in the CEMT classes VIa –b and –c are considered. The push vessels are relatively short, equipped with 3 or 4 engines, unto 5200 kW power, and are constraint to their maximum weight, due to the existence of a tunnel.

First, two cost calculations are performed for push vessels with a 40 m^3 LNG storage tank, respectively in a lowest conceivable price situation and a normal price condition. Subsequently, a cost calculation is estimated for a push vessel with a LNG storage tank of 180 m^3, to meet the special requirements of continuous operated push vessels. In all calculations 4 engines are considered.

TABLE 3: TOTAL INVESTMENT COSTS FOR PUSH VESSELS

Parameter	**Costs (€)**			
	Simple (ideal)	**Push convoy**	**Push convoy Extended range**	***Comment:***
LNG fuel system				*With certainty*
TCS Tank [40 m^3] / [180 m^3]* Bunker station Heating glycol system Process control system Labour Others				**Special design* **Transport etc.*
Engine				*With certainty*
Dual fuel engine Gas valve unit Discounted engine				
Gas valve unit				
Yard				
Socket, venting, piping, alarms. Extra piping				*Possibly more expensive: it is a small vessel.*
Sub total				

Potentially, in a best case situation, a simple design in favorable conditions can reduce the costs of an LNG fuel system by %. Moreover, the total costs of an LNG system can be reduced by %.

2.3 Capital costs

Capital costs consist of interest costs and depreciation, often loan payments, over the initial investment. In this paragraph, the technical and economic life span of LNG fuel systems is investigated. Subsequently, the capital costs are defined, by consultation of a credit approver for IWW vessels of the ABN Amro bank and literature investigation.

2.3.1 Lifetime and value of LNG as fuel

LNG fuel systems consist out of static parts and the components mainly consists out of stainless steels, see Appendix C. Cryonorm equipped the first vessels in 2008, though cryogenic comparable land based systems are already operational for decades, sometime more than 40 years. (Cryonorm, 2015) The technical lifespan of the LNG fuel systems, supplied by Cryonorm, can be expected as no bottleneck for the total technical lifespan of the vessel. (Glorie J. , 2015)

It is expected that engines have the shortest lifespan of an LNG system, due to excessive wear and usage. The technical lifespan of an engine is mainly dependent on the usage and preparedness to invest in overhauls. (Wetering Rotterdam, 2015) The developments of dual fuel engines go fast, but some bottlenecks have yet to be overcome, see Appendix C. Expected is that the potential feasibility of LNG as fuel is in favour of high fuel consuming vessels, hence there is a trade-off between engines lifespan and economic feasibility to move to LNG as fuel. A technical lifespan of the whole LNG system is in this investigation assumed at 15 years.

2.3.2 Economical depreciation, interest costs and residual value

In literature, a minimum economical depreciation period of 10 years is considered for large investments and the purchase of vessels. (Beelen, 2011) On the other hand, the inland shipping market circumstances are acute and loans are difficult to obtain, currently. (Schillemans, 2015) Mr. Schillemans, credit approver at the 'Binnenvaart Unit Nederland" for inland shipping of the ABN Amro bank, explained that the inland shipping policy is prepared to offer loans to move to LNG as fuel, if and only if certain preconditions are met. The ABN Amro is willing to offer these loans, due to the contribution to the Corporate Social Responsibility of the inland shipping sector and the ABN Amro.

ABN Amro, preconditions to obtain a loan for a LNG system: (Schillemans, 2015)

- 10 years economical depreciation.
- 5% interest rate.
- Maximum of 60% loan opposite to the vessels value.
- Proposing a decent and positive business plan.

The vessels' value is determined by the exploitation value of the vessel, which is based on freight margins, freight contracts and vessels productivity. (Schillemans, 2015)

The residual value after the economical depreciation of the LNG systems is difficult to determine, but is mainly dependent on the development of the fuel prices and LNG the supply chain.

2.3.3 Influencing factors on capital costs

To measure profitability of investments calculations can be carried out in various ways. Taking into account parameters, such as the time value of money and variable interest rates, influences the capital costs. Besides, investing personal capital, opposite to loans, can cause different depreciation periods and requisite interest rates.

In this study, the added value, of the investment to use LNG as fuel, will be measured by an internal rate of return (IRR) of >5%, hence a positive net present value, and an economical depreciation period of 10 years.

2.4 Costs of maintenance and repair

In this paragraph, the expected additional costs, by an LNG fuelled inland waterway vessels, of maintenance; repair and oil consumption is investigated and presented.

2.4.1 Maintenance

Additional maintenance costs can be expected by dual fuel engines and the LNG fuel systems.

Dual fuel engine

To determine the additional costs of maintenance, users and experts of dual fuel engines are interviewed and the maintenance service manual are investigated and compared.

The maintenance service intervals for engines are mainly based on the operating hours of the engine. The major maintenance costs are overhaul costs. Maintenance service manual of dual fuel engines and conventional engines shows a slight difference between the interval periods, respectively 20,000 and 25,000 operating hours for CAT/MaK engines. Besides, the overhaul costs are more expensive, a rule of thumb, according to ship repair workshop Wetering Rotterdam B.V, can be used of € ,- (Smidt, 2015) (Wetering Rotterdam, 2015) per head for conventional engines and € ,- per head for dual fuel engines, mainly due ceramic parts. (Wetering Rotterdam, 2015) (Bolier A. v., 2015)

LNG fuel systems

As already described, LNG fuel systems consist out of static parts and the components mainly consist out of stainless steels. Though, inspection and maintenance is required. Inspection, yearly, consists out of leak testing of valves. Maintenance, every two years, consists out of resetting the safety valves and changing a filter. The yearly costs of inspection can be estimated by € ,- and the additional maintenance, every two years, is € ,-, both labour and materials. Outlined of this maintenance are the hoses and break-away-coupling to supply LNG to the vessel, known as LNG bunkering.

2.4.2 Repair

Dual fuel engine

Engine repairs are difficult to define. Bolier, authorized dealer of Caterpillar and MaK engines, expects higher repair costs for dual fuel system, due extra components (Bolier A. v., 2015)

LNG fuel systems

Valves, actuators and piping may leak over time on their seals, membranes or gaskets. The spare part list for these seals, membranes and gaskets are priced in total € ,-. Preventive replacement of these parts is advised after the first leakage occurs, expected after 10 years. Besides the leakage failure, it is expected that some electronic repairs are required over time, such as replacing the computer or sensors. (Cryonorm, 2015)

2.4.3 Lubricants and liquids

Engine lubricants

In literature, lubricant costs are estimated by fixed values of the total consumption costs. Determination of the engine lubricant costs is difficult (Beelen, 2011), and varies between 1% and 5% of the total consumption costs. (Beelen, 2011) (EVO, 2012)

Liquids required for LNG fuel system

If, for some reason, the LNG fuel storage tank is not in cryogenic state, liquid nitrogen is required to cool down the LNG fuel storage tank, otherwise bunkered LNG will directly vaporize and released by the safety pressure valves. The costs for such operation can be estimated on € ,-, which can be considered as operational costs.

Besides, after every time bunkering the piping needs to be purged by nitrogen. This cost item is considered to be incorporated by the LNG bunker prices. Though, a trade-off between tank size and price of bunkering must therefore be considered.

2.4.4 Influencing factors on maintenance and repair costs

In literature, the costs of maintenance and repair are often considered as 3% of the total investment costs of the LNG system. (InnovatieNetwerk, 2013) Though, these numbers can be representative, the indirect costs out of maintenance and repairs are from importance for shipping companies and owners, and vary case by case. (Smidt, 2015)

Two situations can occur during required maintenance and repairs:

- Foreseen unavailable vessel. Cause: maintenance. Effect: no income.
- Unforeseen unavailable vessel. Cause: repairs. Effect: freight penalty.

Continuous operated vessels tend to lower this change on unavailability by all means. (Smidt, 2015) For this reason, shorter overhaul intervals and possibly lowered reliability is undesirable. The trade-off between fuel consumption, bunker counts, higher overhaul costs are therefore different for each type of vessels, which is dependent on its operational parameters and the market they serve.

3 BUSINESS CASE ANALYSIS

In this chapter, a business case analysis (BCA) of using LNG as fuel for inland waterway vessels is performed. In this BCA the cost items, as presented in chapter 2, are used. This BCA is performed out of a best case situation, whereby any obstacles, additional marginal costs and risks by using LNG as fuel are neglected. These neglected aspects will be investigated in chapter 4.

Chapter 2 has shown that the initial investment costs to move to LNG as fuel is high. To consider LNG as a commercial solution these investment costs needs to be earned back, by mainly fuel costs savings. As studied in chapter 2, inland waterway vessels use relatively little fuel. This BCA will show the commercial eligibility of using LNG as fuel for different inland waterway vessels. This way, the preconditions to have a profitable investment, of this long-term project, are determined. It can be expected that the commercial feasibility for some vessels will be difficult, by low fuel consumption and high investments, anyway. Henceforth, these vessels can be excluded in the sequel of this investigation on their commercial potential. On the other hand, the eligible vessels will be further investigated, on obstacles and opportunities, in able to consider LNG as a commercial fuel solution.

This research is intended to determine business opportunities of LNG fuel systems, therefore the business case analysis reviews in which circumstances moving to LNG as fuel would add value to a shipping company. Whether it is better to invest into another project is scoped out.

3.1 Method and parameters of the business case analysis

In this business case analysis (BCA), the additional cash flows over a period of time are analysed. These additional cash flows consist out of incoming and outgoing cash flows, respectively positive and negative cash flows, based on the cost items in chapter 2. In this BCA the required incoming cash flows consist out of the potential fuel costs savings. On the other hand, outgoing costs consist mainly on the capital costs and additional maintenance and repair costs.

With this BCA the required incoming cash flows by fuel costs savings are determined. The fuel cost savings consist out the potential fuel costs savings multiplied by a vessels' fuel consumption. By opposing the additional negative cash flows to the additional positive cash flows the profitability of an investment can be determined. As already concluded, LNG as fuel requires a high investment and the payback period is 10 years, hence this transition is considered a long-term investment. For this reason, the present values of positive and negative cash flows over a period of time are incorporated in the BCA. By the sum of all present values, of positive and negative cash flows over the economic depreciation period, the net present value (NPV) of this transition can be determined. It can be expected that by a positive NPV will add value to a shipping company, hence, the business case of using LNG starts. In this business case analysis the required positive cash flows are determined by equalizing the cash flows to a NPV of zero. For this calculation a financial tool is developed, see Appendix D, whereby the considered costs items can be analysed and can be compared in a graph, hence the yield for each vessels can be determined.

In this financial tool, the costs items are separate into fixed and variable costs. The variable costs are related to the fuel consumption per vessel, subsequently, if necessary, based on a current fuel price of LSMGO of €422.- per m^3.

The parameters used in the business case tool are as follows:

- Fixed costs:
  - Discount rate
  - Period
  - Investment
  - Maintenance and repairs
- Operational Expenditures:
  - Maintenance and repairs
  - Fuel efficiency of engines
  - Replacement rate of LNG, by pilot fuel injection

First, a limited number of parameters are incorporated within the financial tool to determine the starting points of the business cases. The reason to just incorporate a limited number of parameters is that hereby the best case situation can be determined by a greater certainty. In this best case situation, the greatest thinkable commercial potential of using LNG as fuel is defined. Second, a sensitive analysis is performed to determine the possible impact of the other parameters and influencing factors, out of paragraphs 2.1.3, 2.2.4, 2.3.3 and 2.4.4. Final, the business case analysis is performed to eventually define business opportunities of LNG fuel systems.

3.2 Business cases of LNG as fuel per vessel size

In this paragraph, the business cases per vessel size, by using the business case tool, are presented. The business cases are determined in the best case situations, whereby any obstacles and maintenance and repair costs are excluded. The cost items, as presented in chapter 2, are used to define the business cases. This results into a best case situation, in a situation whereby the LNG fuel systems are as cheap as possible. Subsequently, the business cases are defined by the current prices of LNG fuel systems, both of simple and of special design.

Calculation conditions, by a limited number of parameters (see Appendix D):

- Fixed costs:
  - Discount rate: 5% (ABN Amro)
  - Period: 10 years (ABN Amro)
  - Investment expenses: according to paragraph 2.2.5
  - Maintenance and repairs (excluded)
- Operational Expenditures
  - Maintenance and repairs (excluded)

Figure 7 shows the business cases of LNG as fuel for the motor vessels in the CEMT class IV and V. The curved green, red and light blue line represents the tipping points whereby the business case starts, at these points the NPV is zero. The investment tends to be potentially profitable if the circumstances are above the tipping point lines. Subsequently, the highest annual fuel consumption per type of vessel in literature or of the calculation based on the roundtrip is shown in Figure 7, by the brown lines, which corresponds to the findings out of Chapter 2. The assumed current economic potential is also shown in Figure 7, which corresponds with the findings in Figure 3. At last, the current, by June 2015, LSMGO price is shown by a vertical line, which corresponds with €422,- per m^3 LSMGO. Figure 7 facilitating to use the successive graphs in the same manner.

Rijn-Hernekanaalschip and Large Rhine Vessel (LRV 110m)

Even with a simple design and price differences between the fuels as high as the current price of LSMGO, it is financially not profitable with the financial preconditions for the Rijn-Hernekanaalschip to move to LNG as fuel. With regard to the Large Rhine Vessel (110m), it requires approximately a 40% less difference between the fuels, compared to the RHK vessels.

Besides, additional barriers, costs for maintenance and repair are not taken into account. On the other hand, longer economical depreciation period could cause a larger area for profitability.

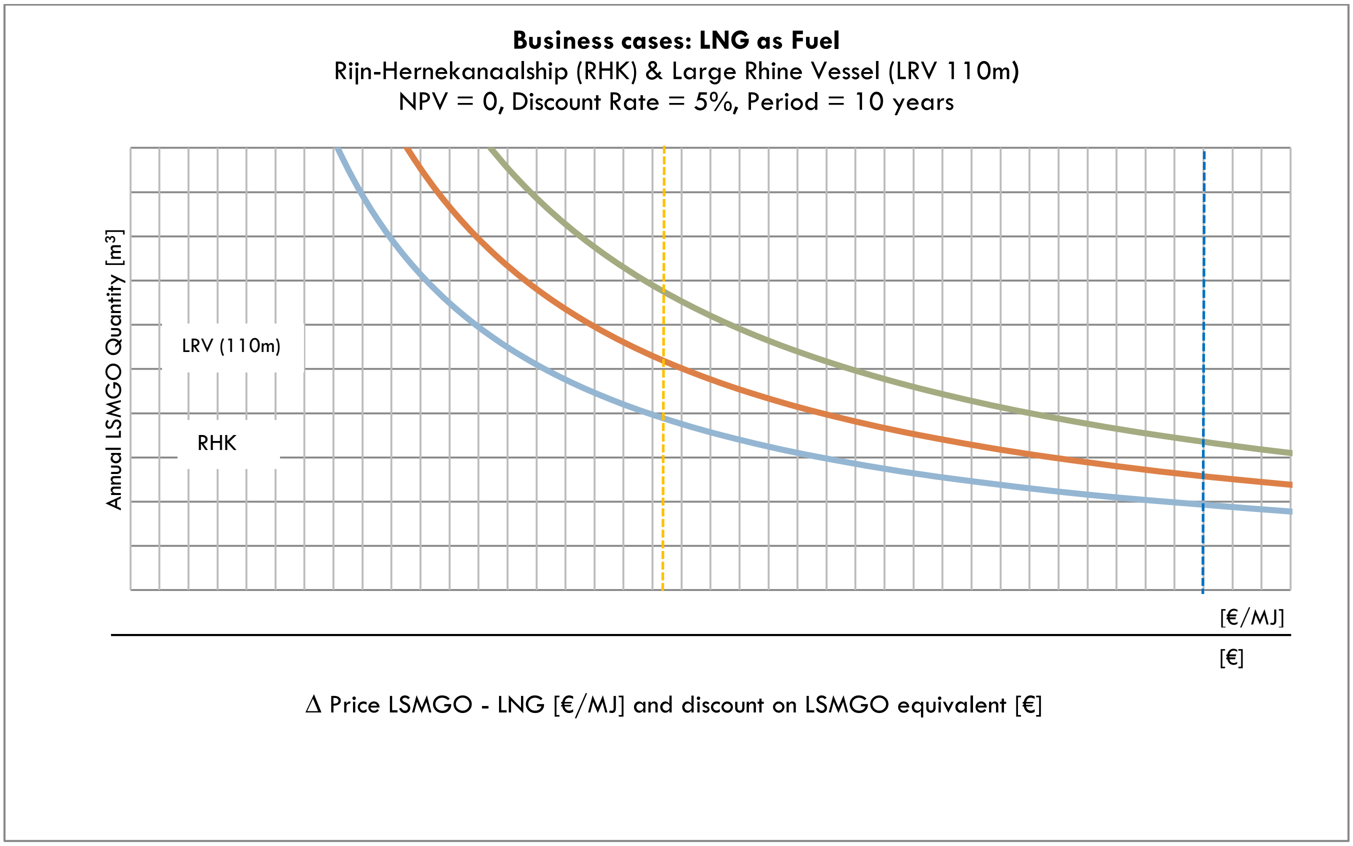

FIGURE 7: BUSINESS CASES RIJN-HERNEKANAALSCHIP & LARGE RHINE VESSEL (110M)

Large Rhine Vessel (LRV 135m), Koppelverband (KV) and Large Tanker

Figure 8 show that there is a thin business case of LNG as fuel for these larger motor vessels. In the best case situation, whereby the current economic potential is reached, the business case starts for these motor vessels with an annual fuel consumption equivalent to m³ LSMGO. At this point, any obstacles or additional costs, such as maintenance and repair, are neglected.

If normal LNG system prices are considered and the current economic potential is reached the business case starts for motor vessels with an annual fuel consumption equivalent to m³ LSMGO. Taken into account the highest conceivable fuel consumption for these motor vessels, as calculated in section 2.1, the business case for the LRV (135m) and the Koppelverbanden requires even a fuel discount equivalent to € .- per m³ LSMGO equivalent. With a simple design, it still requires a fuel discount of € - per m³ LSMGO equivalent.

Taken into account the economic potential of €216.- per m³ LSMGO equivalent and the highest fuel price ever, € 722.- per m³ MGO, the price advantage of LNG is approximately 30%. At this point, an equivalent fuel consumption of m³ LSMGO is required.

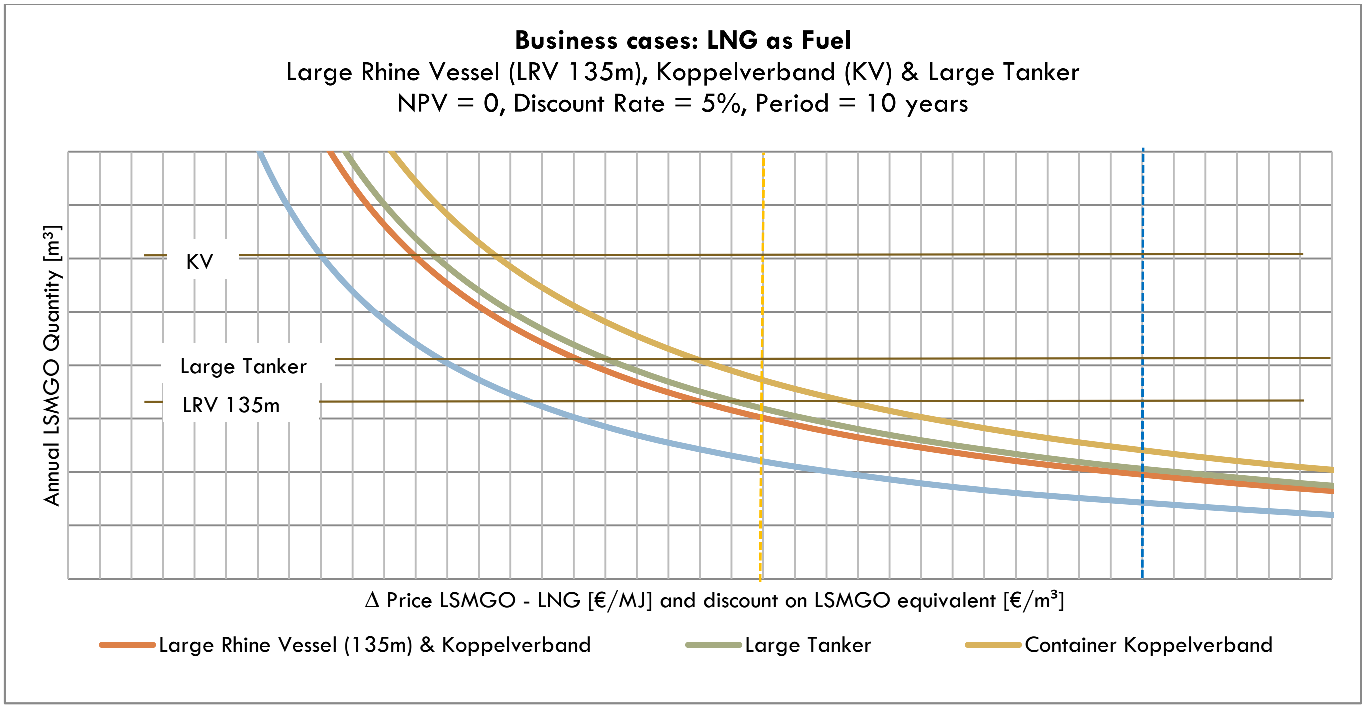

FIGURE 8: BUSINESS CASES OF LARGE RHINE VESSEL (135M), KOPPELVERBAND (KV) & LARGE TANKER

Figure 8

Push convoys

Figure 9 shows the business case analysis for push vessels. The business case starts, with a fuel price advantage as high as the current economic potential of LNG, the business starts from an annual fuel consumption equal to m³ LSMGO. Though any indirect costs, maintenance costs, repair costs and other obstacles are excluded from this calculation.

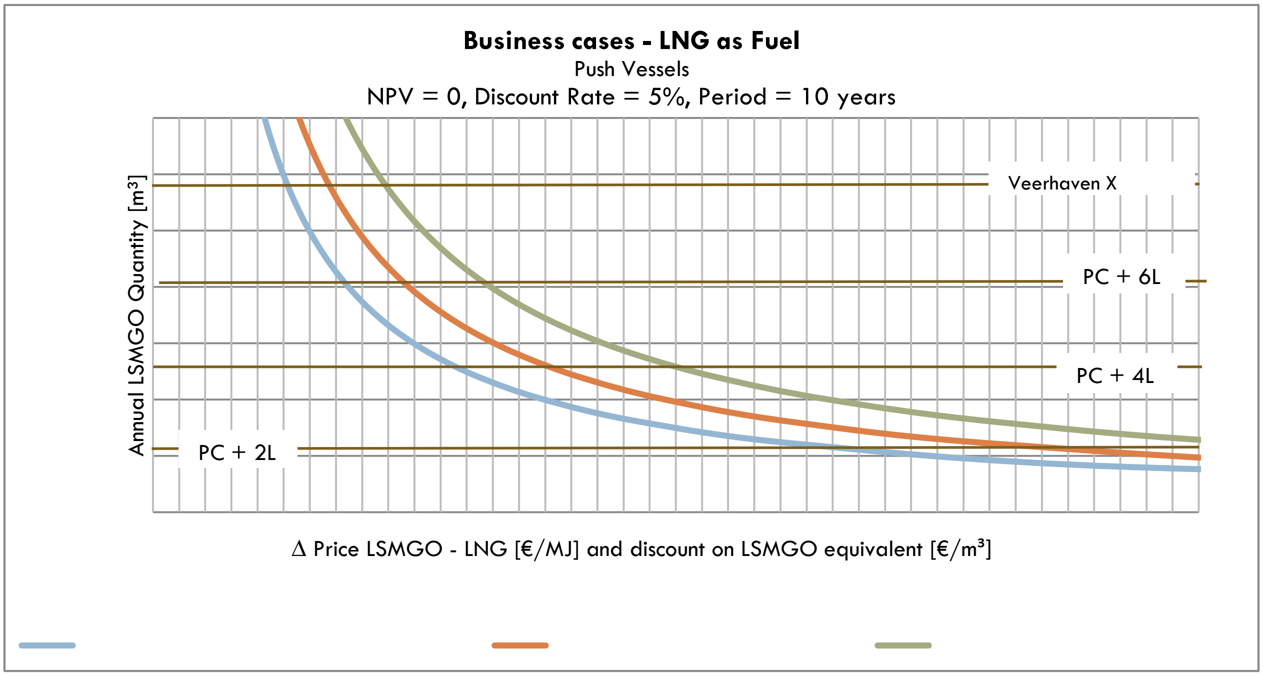

FIGURE 9: BUSINESS CASES OF PUSH VESSELS

Conclusion of the financial assessment

Although the business case tool has included limited parameters and any obstacles are neglected, the business case of LNG as fuel for inland waterway vessels is very thin. In favorable conditions two types of vessels are first eligible by their operating parameters, namely:

- Motor vessels with a CEMT class VI or higher with an annual fuel consumption of more than m^3 LSMGO.
- Push vessels with an annual fuel consumption more than m^3 LSMGO.

Though the potential business cases are very thin, these vessels are considered to have the most potential, hence the largest part of their fleet becomes potentially eligible.

3.3 Sensitivity analysis

For the first business case analysis, limited numbers of parameters are used. Moreover, the value of the parameters can vary. This sensitivity analysis will examine the influence of these parameters, though any obstacles or opportunities to move to LNG as fuel are still excluded.

Longer economical depreciation period

For this calculation, a Large Tanker, or related Large Container Vessel, is analyzed on its sensitivity by an economical depreciation period of 15 and 20 years, compared to the previously considered period of 10 years. This longer economical depreciation period could be used if private capital is used or the preconditions for loans are changed.

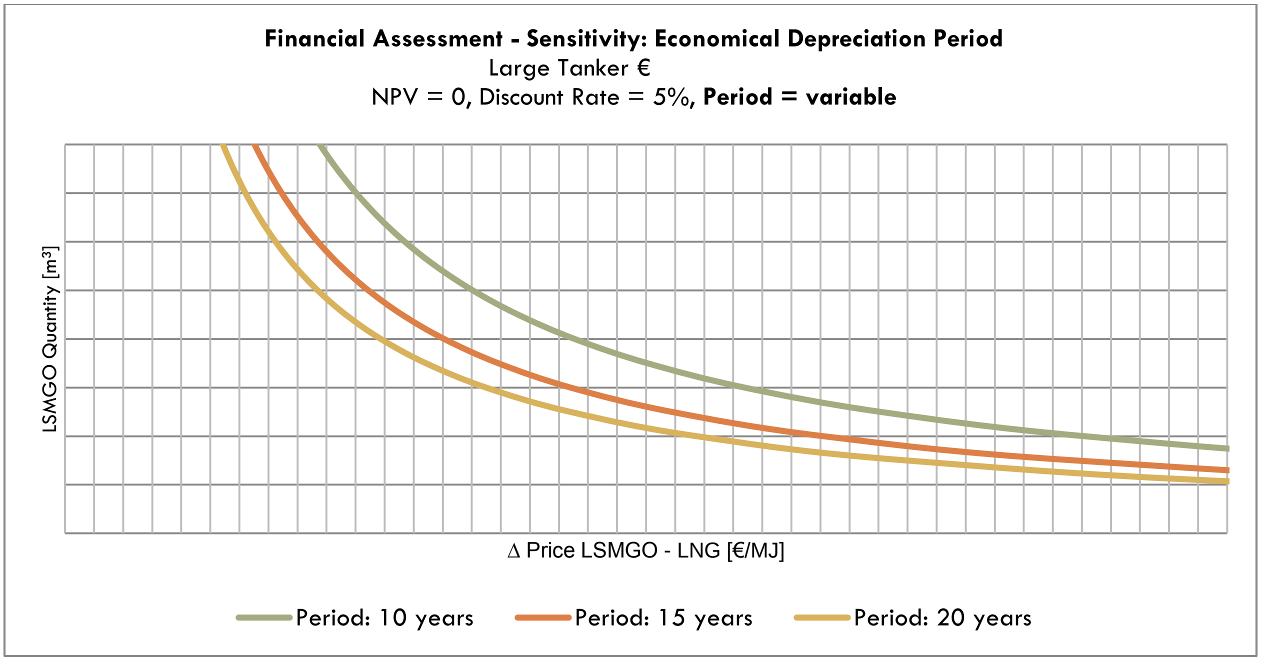

FIGURE 10: SENSITIVITY ANANLYSIS: LONGER ECONOMICAL DEPRECIATION PERIOD

Figure 10 show that a longer economical depreciation period can enlarge the business cases of LNG as fuel. Vessels, with annual fuel consumption of an equivalent of m^3 LSMGO, can have less favourable price differences of fuel, unto € .- per m^3 LSMGO. This is %, based on a LSMGO price of €422,- per m^3.

Including maintenance and LSMGO replacement rate

For this calculation a Large Tanker, or related Large Container Vessel, is analyzed on its sensitivity by taking into account the direct costs of maintenance and the replacement rate of diesel by 95%, respectively 5% pilot fuel injection. The maintenance costs for the LNG fuel system and overhaul costs are included and compared to the basic scenario in Figure 11. This sensitivity analysis shows that at an annual use of m^3 LSMGO the additional price advantage of LNG must be approximately €30.- per m^3 LSMGO.

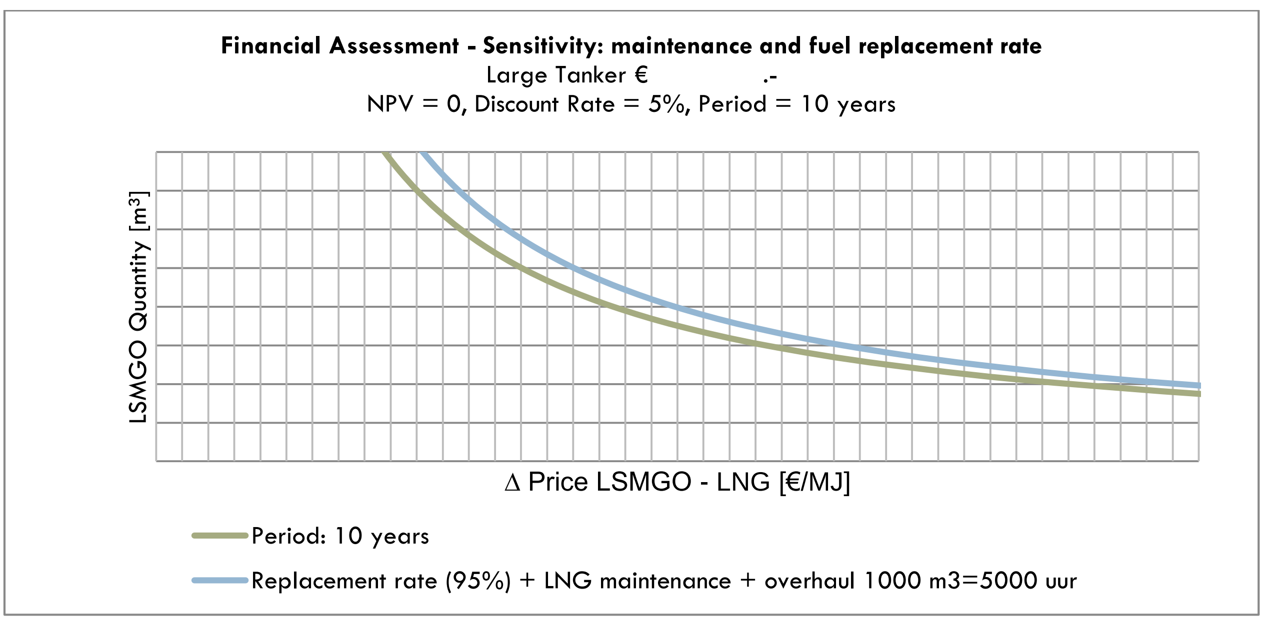

FIGURE 11: SENSITIVE ANALYSIS OF MAINTENANCE AND FUEL REPLACEMENT RATE (5%)

3.4 First eligible vessels (update)

Appendix E shows a graph with the yearly bunkered volume LSMGO for motor vessels, mainly for Rijn-Hernekanaalschip and Large Rhine Vessels (95 – 135m, mainly 110m). In this graph, individual bunkering volumes, with more than 250 m³ LSMGO each, are shown. This graph shows that the estimated 'highest conceivable fuel consumption' in paragraph 2.1 is representative for a very few vessels, hence this is expected to be the same for other vessels, such as Koppelverbanden, in this investigation.

To determine the first eligible vessels the fleet in Appendix E is investigated. Figure 12 shows the fleet prognosis, on eligibility, for vessels with a length of up to 110m with a BCA for a standard design, hence one engine is considered. Large Rhine Vessels ≤110m can be equipped with two engines. Hence, this fleet prognosis carries some uncertainty. On the other hand, these fleet prognosis can be read in conjunction with Figure 13, whereby Large Rhine Vessels with two engines are considered.

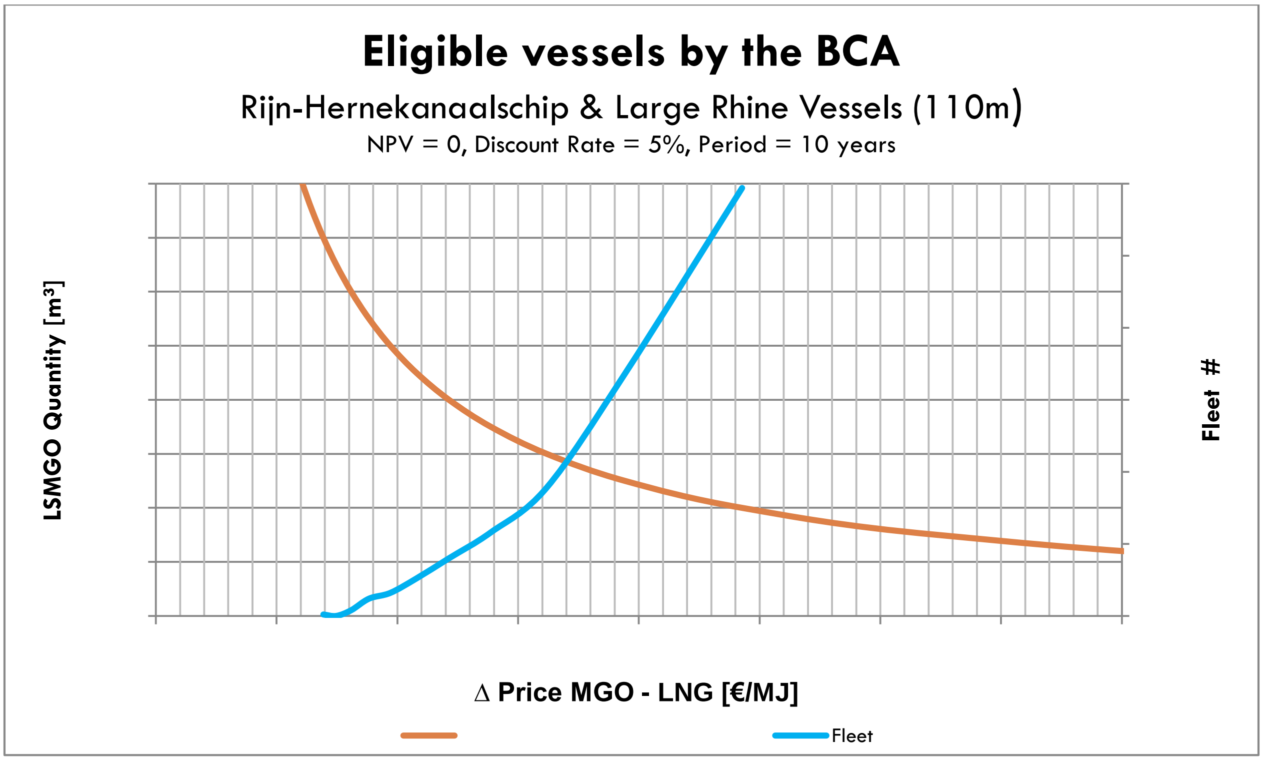

FIGURE 12: ELIGIBLE VESSELS, CURRENT FLEET, MOTOR VESSELS ≤110M

Both, Figure 12 and Figure 13, show that at a price advantage of €/MJ, which is the considered as a reference value in this study, a maximum of vessels are eligible to move to LNG as fuel. These vessels are responsible for a major part of the European fleet, in terms of 2400 vessels in total. (Binnenvaart, 2015)

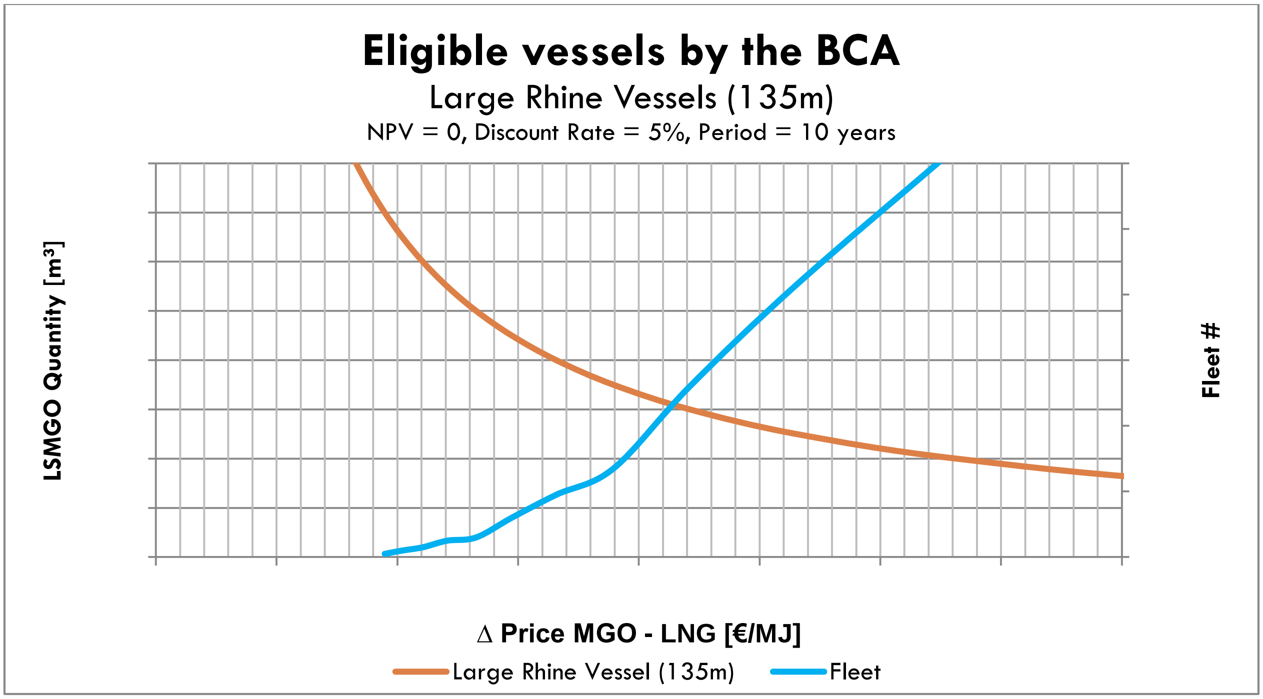

FIGURE 13: ELIGIBLE VESSELS, CURRENT FLEET, MOTOR VESSELS OF 135M

It can be concluded, that the highest conceivable annual fuel consumption of vessels, shown in paragraph 2.1, is representative for a very few vessels in the fleet. Therefore, it can be assumed that a few Koppelverbanden, Large Tankers and Large Container Vessels get eligible more quickly to use LNG as fuel than already estimated. Though, the current fleet of such motor vessels is relative small, approximately 300 vessels in total. (Binnenvaart, 2015)

For the main part of the fleet it can be considered that larger motor vessels are more eligible, based on the main characteristics of the fleet, to potential use LNG as fuel. On the other hand, the total fleet of the Rijn-Hernekanaalschip and Large Rhine Vessels (95 – 135m, mainly 110m) is enormous. Hence, the absolute number of eligible vessels to potentially move to LNG as fuel by these considered vessels is larger. Out of this, it can be expected that if some Rijn-Hernekanaalship and Large Rhine Vessels become eligible to use LNG as fuel, they will rather be retrofitted with an LNG fuel system, due to the low share of vessels that consumes enough.

Set out in the previous paragraph, motor vessels, with a CEMT class VI or higher, become the first eligible vessels to move to LNG as fuel by consideration of their fleet properties. Wherein, the few vessels with enormous fuel consumption, in terms of the estimated highest conceivable fuel consumption, are excluded. Out of this, it can be expected that newly built vessels will move to LNG firstly.

4 OBSTACLES AND OPPORTUNITIES OF LNG

In chapter 3, the most eligible vessels to move to LNG as fuel are appointed. With an intention to consider LNG as a ready fuel solution for these inland waterway vessels, some obstacles will have to be overcome. Moreover, opportunities can support the use of LNG as fuel for all vessels sizes. Obstacles are mainly characterised by financial eligibility and supply chain of LNG as fuel. In contrast, opportunities can contribute to an acceleration of the use of LNG as fuel for inland waterway vessels.

In this chapter, the current obstacles and opportunities for shipping companies to move to LNG as fuel are investigated. With this information, developments and trends are made clear, in order to define supposable scenarios. Along these lines, the business opportunities of LNG as fuel for inland water vessels are defined in chapter 5.

To capture the obstacles and opportunities of importance, as many different facets are explored. The results are presented in a framework of 6 aspects, based on Shell's scenario approach (Shell, 2013). This approach is used by Shell to determine their oil and fuel markets scenarios; hence it is assumed that these aspects will also cover the use of LNG on small scale for inland waterways. The aim of this framework is that plausible scenarios can be developed and implications can easily be qualified and examined, as outlined, in chapter 5.

The framework consists out of 6 aspects, which are:

- Environment
- Economy
- Finance
- Corporate Social Responsibility (CSR)
- Technology
- Politics

4.1 Environment

LNG as fuel could be a solution to meet possible emission targets and lower engine noise levels. A potential emission reduction of 25% for CO_2, 97% for NOx and 100% for PM_{10} (KIM, 5/2015) can be achieved by using LNG as fuel for inland waterway vessels.

Methane slip

4.1.1 Influencing environmental factors for the use of LNG as fuel

Though the emphasis is on dual fuel propulsion systems, other propulsion systems have advantages on their emissions, but for now, by the fuel security of a dual fuel propulsion system and it is favourable investment cost. . From this perspective, conversions of conventional engines to gas fuelled engines, known as engine retrofit, can be considered as a limited opportunity.

For some ports, port fees for inland waterway vessels are lowered if the vessels comply with certain favourable environmental performances and even more if these vessels are in the possession of relevant certificates. Assuming that the considered vessels, set out in chapter 3, already have engines which comply with the CCR2 emissions regulations, only certificates contribute to a positive incentive for ship owners. The certificates, applicable in Western Europe, are the Green Award Certificate and the Environmental Ship Index (ESI). With a Green Award Certificate, which costs €205.- annually, including the subsidy by the Dutch Ministry of Infrastructure and Environment for the first 5 years, the port fees of Rotterdam can be lowered by approximately 5% by using LNG as fuel, depending on the base case. This results into a benefit of approximately €275.- annually, including the costs of the subsidized certificate costs, whereby a vessels with a deadweight of 3000 ton and a full time visit of the Port of Rotterdam was considered. The current benefits of such incentives can be neglected, but it is an incentive.

4.2 Economy

In this paragraph, the obstacles and opportunities are presented of the economic aspects. First, the developments in the inland shipping market are investigated by sector reports and visions of banks, ABN Amro and Rabobank. Second, the investments and developments of the LNG supply chain are analysed and presented. Finally, the causality between the economic developments, fuel prices and the use of LNG as fuel for inland waterway vessels is analysed.

4.2.1 Vision of the inland waterway market by banks

Investments in new inland vessels in front of the economic crisis of 2008 led to excess overcapacity today, especially for tankers. Currently, the market circumstances are acute, freight margins are low, freight tariffs are lower compared to the prices in front of the crisis and the total fleet can't fulfil their financial liabilities. (ABN, 2013) A slight increase in demand will eventually meet the current supply, expected by the ABN Amro and Rabobank in 2020. (ABN, 2013) (Rabobank, 2015) The long term prognosis of the inland shipping market can be considered as uncertain.

4.2.2 Developments of the LNG supply chain, both small and large scale

Natural gas is an important source of energy in Europe, especially in the Netherlands, since the discovery of gas fields. Gas solutions can contribute to meet the emission requirements by the European Union. (TKI-Gas, 2015) Part of these gas solutions is imports of LNG from overseas to Europe, by using LNG carriers and LNG terminals.

"On Maasvlakte in Rotterdam, Gate terminal has built the first LNG import terminal in the Netherlands. The terminal will have an initial throughput capacity of 12 billion m3 (bcm) per annum and will consist of three storage tanks, two jetty's and a process area where the LNG will be regassified. Annual throughput capacity can be increased to 16 bcm in the future. The terminal dovetails with Dutch and European energy policies, built on the pillars of strategic diversification of LNG supplies, sustainability, safety and environmental awareness. The initiators and partners in Gate terminal are N.V. Nederlandse Gasunie (Gasunie) and Koninklijke Vopak N.V. (Vopak)" (Gas-unie, 2015, p. Website)

"Production of natural gas in northwest Europe, including the Netherlands, is declining yet demand is continuing to rise. Gas will have to be imported from other regions, mainly by pipeline from Russia and in the form of liquefied natural gas (LNG). Both options will be necessary to meet the projected demand. The initiators of the proposed open (i.e. independent) LNG terminal believe Gate terminal will be an important factor in importing gas from other countries and sources into Europe. It will increase the security of supplies and also enable new players to enter the European gas market. Moreover, the terminal's direct connection to the national natural gas transmission network will consolidate the Netherlands' position as a major European hub for gas trade and distribution." (Gas-unie, 2015, p. Website)

Following the LNG terminals in Europe, new developments and use of small scale LNG-solutions became commercially attractive. (Zijverden, 2015) (Cryonorm, 2015) The Gate terminal in Rotterdam started in second half of 2014 by building the break bulk part to supply LNG to small and mid-scale LNG customers, which is expected to be operational in fourth quarter of 2016. It is expected that the break bulk terminal will have a maximum of 280 berthing slots annually for both mid and small scale use. From this development, it can be expected that satellite plants are developed among the main inland waters and LNG bunkering becomes flexible. Investments involved with LNG terminals and break bulk terminals are high. These investments, both subsidies and company investments, must be earned back by the involved actors. LNG as fuel for inland waterway vessels is one of those solutions to earn these investments back.

Besides non-profit organizations, several new market players and existing companies are investing in the LNG supply chain. In example, on large scale gas exploration; Shell took over BG in 2015 and some small scale LNG supply chain actors, such as LNG24, TitanLNG and Primagaz, Cofely-gdfsuez are investing in the supply chain. The current LNG supply chain is still in its deadlock and customers are cautious to move to LNG as fuel. Resolving this deadlock is essential for actors who already invested in the LNG supply chain, they have to earn back their investment back. All these actors have a shared economic interest to find customers to resolve the LNG deadlock. (Cryovat R. v., 2015)

4.2.3 Influencing economic factors for the use of LNG as fuel

Economic factors are from great influence on the small scale use of LNG. An upward economic cycle can accelerate the freight margins and prices in advantage for shipping companies. From this situation, shipping companies can fulfil their financial liabilities better and more scope for investment arises.

An extensive small scale LNG supply chain will resolve the obstacles of bunkering fuel and probably lower the retail costs, to meet the current economic potential of LNG, which is set out in chapter 2. Though, the developments of the small scale LNG supply chain are associated to the large scale LNG network and developments. Economic growth can cause extra demand on energy and therefore developments in the large and small scale LNG network.

4.3 Finance

Financial resources are essential to move to LNG as fuel. The inland waterway shipping market circumstances are acute and loans are difficult to obtain. (Schillemans, 2015) In this paragraph, the obstacles and opportunities of the financial aspects are presented. First, the investment readiness and capability by shipping owners to potentially invest is investigated. Secondly, indirect costs of using LNG as fuel are examined, such as intake freight capacity, bunkering time, maintenance time, repair time, etc..

4.3.1 Financial strength and readiness of shipping companies

The current shipping policy of the ABN Amro is used in the business case analysis in chapter 3. The current loan conditions have an interest rate of 5% over an investment period of 10 years. The preconditions to obtain this credit consist out of a maximum loan to value rate of 60%, whereby the vessels value is determined by its exploitation value after investment. (Schillemans, 2015) The exploitation value is determined by the freight margins and the vessels productivity over its reaming lifetime.

From this perspective, the eligibility of such LNG fuel systems is for all owner-operators and shipping companies difficult. In paragraph 2.2.5, the investment capital required to move to LNG as fuel is determined on for an Large Rhine Tanker Vessel (100m). Even if this vessel is fully paid off and the business case is equal, Net Present Value of zero, it is still doubtful if the loan to value rate is lower than 60%. Private capital is therefore required and possible deductions on taxes can be used, such as the Dutch Energie-Investerings-Aftrek (EIA), which can be beneficial of approximately 10% of the total investment costs.

4.3.2 Price development of LNG system

In Appendix C, an extensive analysis of the price of LNG fuel systems is presented. The investment costs to move to LNG for a simple design in an ideal situation is already presented in paragraph 2.2.5. It is not expected that this price can be lowered over the next 10 years, due increasing regulations. On the other hand, an improved LNG supply chain can ensure that a smaller LNG fuel storage tank is sufficient. Hence, any lowered loan payments can be weighed against the number of bunkering, provided by an equation in Appendix C. , the total costs of an LNG system can drastically become more expensive,

4.3.3 Indirect costs of using LNG as fuel

The direct costs of using LNG as fuel are determined in chapter 2, though the transition to move to LNG will also change the indirect costs during shipping. Indirect costs may arise, for example during maintenance and repair. During this maintenance the vessel cannot generate revenues and they might have to pay their staff. The importance of indirect costs differs per shipping company, the market they serve and the productivity of the vessel. (Smidt, 2015) Vessels productivity depends on the capacity usage and how intensively the vessel is operated. (Beelen, 2011, p. 79) In this subparagraph, the indirect costs of using LNG as fuel are presented, which are investigated by interviews and literature study. Opposite to indirect costs by using LNG as fuel are indirect savings or indirect revenues.

Indirect costs of capacity reduction by LNG fuel system

Vessel productivity depends on capacity usage and operational intensity of the vessel. (Beelen, 2011, p. 79) Extra weight and volume of LNG systems affect the capacity of IWW vessels. A vessels´ maximum capacity is often constraint by deadweight. On the other hand, container vessels have low density cargo, constraining the maximum capacity by its volume. (Beelen, 2011)

It is believed that the share of empty trips remain unchanged in application of an LNG system. Moreover, there are several thoughts about how to deal with load factors by a changed maximum capacity.

For example, a load factor of a container vessel is often not higher than 95% of the total capacity, if there's a capacity reduction in terms of 2%, after installation of an LNG system, the effect could be:

1. Load factor stays 95%
2. Load factor becomes 97%

For tankers and dry bulk vessels it is easier to deal with capacity reduction. These ships are often filled to their maximum deadweight. A calculation is performed to determine the capacity reduction by having an LNG fuel system. (see Appendix C)

The capacity reduction is dependent on the vessels size, type and the requirements to the LNG fuel system. For a container Large Rhine Vessel (110m), the capacity reduction is 4 TEU, out of the maximum capacity 208 TEU, which is almost 2%. In case of a Large Rhine Vessel (110m) tanker the LNG fuel system reduces the deadweight with 0.6%. It can be expected that the impact on capacity of LNG fuel systems becomes smaller on larger vessels.

Scenario calculation:

Indirect costs of maintenance and repair

During maintenance and repair, vessels costs money without getting revenues, due to the lack of productivity. The direct costs of maintenance and repair are estimated in paragraph 2.4. Distinction can be made between scheduled and unplanned maintenance, translating into foreseen unavailability and unforeseen unavailability of the vessel.

Paragraph 2.4 has shown that the maintenance interval is shortened for dual fuel engines. An overhaul will take at least 5 days (Wetering Rotterdam, 2015). The impact of maintenance time on the indirect costs differs per type of ownership and productivity of the vessel.

Besides this scheduled maintenance, unforeseen unavailability of the vessel can cause major indirect costs. Unforeseen unavailable vessels can even cause a breach of contract accompanied with probably a penalty clause (Smidt, 2015) Hence, especially for charters and continuously operated vessels, the vessels' reliability is of great importance. As a result, shipping companies with vessels in continuous operation are reserved to use unproven technologies (Smidt, 2015)

4.3.4 Bunkering costs and logistics

As shown in paragraph 4.2.2, the LNG supply chain is under development. The first mid scale LNG bunker location will be operational in Rotterdam on the Maasvlakte 2 in the fourth quarter of 2016. It is expected that the break bulk terminal will have a maximum of 280 berthing slots annually. Depending on a trading pattern of the vessel, the indirect costs to navigate to the break bulk terminal must be taken into account. Besides, the bunker lines used for bunkering must be renewed time to time. Satellite bunker plants, small scale, can be expected along the Rhine in the future, after opening of the Break Bulk Terminal and probably after the availability of a bunker barge. The satellite bunker plants can improve the LNG bunker flexibility and times.

4.3.5 Influencing financial factors for the use of LNG as fuel

The equipment, required to use LNG as fuel, is capital intensive and the benefits are uncertain, currently. The investment costs to move to LNG as fuel is such high that there is a problem with financial eligibility. It is expected that the eligibility will be in favour for larger vessels, relative lower investment costs and potentially more benefit, by fuel cost savings. On the other hand, the indirect costs are not in favour four continuous operated vessels, which are mainly large. Besides, the energy efficiency of LNG fuelled engines is probably different, and they might be lower.

4.4 Corporate Social Responsibility

In this paragraph, the social aspects of using LNG as fuel are presented. LNG as fuel has the image that it is good for the environment. Companies and governments use this environmental sustainable image for their Corporate Social Responsibility program. The value of this aspect is currently unknown for customers of shipping companies. Probably large companies, such as Heineken, are more sensitive to their public perception.

Besides the Corporate Social Responsibility of using LNG as fuel, some shipping owners will move to LNG as fuel because they think it is en vogue or they have an interest in the LNG supply chain. Another incentive to move to LNG as fuel could be the first movers' advantage. First movers with an interest in the use of LNG as fuel can be expected and are so called launching customers.

4.5 Technology

In this paragraph, the technological obstacles and opportunities are presented. Appendix C shows an extensive investigation of the technical requirements for using LNG as fuel. First, the requirements and opportunities for LNG fuel systems are presented. Subsequently the findings out of Appendix C are presented.

4.5.1 Requirements of LNG fuel system

As concluded in paragraph 3.4, Large Tankers, Koppelverbanden and Push Vessels will be the first vessels that will be economical profitable to move to LNG as fuel. The obstacles have to be overcome, such as bunkering places and indirect costs. Besides, these vessels operate on a more continuous basis, therefore total storage capacity of LNG and bunker times are of greater importance.

4.5.2 Propulsion system and vessel

The financial profitability of using LNG as fuel determined by the profitability out of fuel, hence the fuel consumption is important aspect. A new to be built fuel efficient vessel, for example a new to be built vessel with a diesel-electric propulsion system, is therefore less attractive to move to LNG as fuel. Besides, in this case a double LNG fuel system is required.

4.5.3 Influencing technological factors for the use of LNG as fuel

The investment costs required depends mainly on the type of vessel, size of vessel and the operating profile. For already fuel efficient vessels, the advantage of using LNG as fuel is less attractive.

4.6 Politics

LNG as fuel could be a solution to meet possible emission targets, energy independency and lower noise levels, both local and global. A potential emission reduction unto 25% for CO_2, 97% for NOx and 100% for PM_{10} (KIM, 5/2015) can be achieved by using LNG as fuel for inland waterway vessels.

Basically, LNG as a sustainable fuel solution should be attractive to move to for shipping companies. On the other hand, barriers can withhold shipping companies to move. Policy measures could be used in certain cases to take away these barriers to resolve the deadlock or promote opportunities.

In this paragraph, emissions targets, potential emission regulations, policy options and barriers to move to LNG as fuel are investigated.

4.6.1 European commission – White Paper on Transport

Emission targets for transport are set by the European Union and are presented in the White Paper on Transport of the European Committee. The emission goals are presented by their quotes in this section.

"The EU has called for, and the international community agreed on, the need to drastically reduce world greenhouse gas (GHG) emissions, with the goal of limiting climate change below 2 °C. Overall, the EU needs to reduce emissions by 80–95% below 1990 levels by 2050, in the context of the necessary reductions of the developed countries as a group, in order to reach this goal." (Commitee, 2011, p. 6)

"The environmental record of shipping can and must be improved by both technology and better fuels and operations: overall, the EU CO2 emissions from maritime transport should be cut by 40% (if feasible 50%) by 2050 compared to 2005 levels." (EC & commission, 2011)

The above stated ambition is stated for the emission of just CO2. Besides, there is an EU-directive for engines of inland waterway vessels for abatement of CO, NOx and PM_{10}. (KIM, 5/2015) The IWP-5 directive could even abate emissions on total hydro carbons.

4.6.2 Policy options to reduce energy use and emissions for inland waterway vessels

The benefits and costs of using LNG as fuel, if and only if assumed as a cleaner fuel, should be at the same party. Currently, there is no benefit for shipping companies to move to LNG as fuel. Policy options can be used to take away this barrier by abatement of emission charges. On the other hand, the Mannheim Convention is a legal barrier for introducing these kinds of policy options.

Besides the direct policies on emissions, there are policy options to take away barriers of the investment readiness by shipping companies. Though, their financial eligibility is already limited and the potential savings are low, inherent to relative low fuel consumption of inland waterway vessels. Because of this, it is more thinkable that policy measures are introduced to promote cheaper and less material intensive emission solutions to meet the possible new emission abatement regulations.

4.6.3 European Union emissions regulations

As investigated and presented in subparagraph 1.1.3, it is unclear which and when stringent emissions regulations can be expected. Yet, there is proposal to stringent the emissions of engine used for inland waterway vessels in 2021, by the possible new *non-road mobile machinery* of the European Committee, known by IWP-5. Though, it is doubtful whether this regulation is achievable for the current inland waterway fleet. Besides, there is abatement on total hydrogen carbon emissions within this proposal.

4.6.4 Subsidies and incentives

The current five operational LNG fuelled inland waterway vessels are subsidized by different governmental funds. These funds were temporarily and have probably the purpose to resolve the LNG deadlock and to become familiar with LNG as fuel.

In general, policy options to save energy are more effective than policy options to promote the use of sustainable energy. (KIM, 5/2015) LNG as fuel doesn't bring any fuel savings and gas is not a renewable energy source, though it is reputably is more sustainable than the current used LSMGO.

4.6.5 LNG supply chain

The large scale LNG supply in the Netherlands is partly developed by governmental business, by the Gasunie, for strategic diversification of LNG supplies, sustainability, safety and environmental awareness. The small scale LNG supply chain can probably profit out of this developments, with low LNG prices in effect.

4.6.6 Influencing factors for the use of LNG as fuel

The long term policy options for LNG as fuel are limited, due the capital intensity and limited profit by shipping companies itself. Structural subsidies are not expected, though funds like the Norwegian NOx fund can give a boost to the use of LNG as fuel, but it has a legal barrier to introduce. On the other hand, discount on port fees can cause an incentive.

5 BUSINESS OPPORTUNITIES OF LNG FUEL SYSTEMS

In this chapter, scenarios are defined and were possible examined by the business case analysis in chapter 3. Obstacles and opportunities described in chapter 4 are used to develop these scenarios. Furthermore, the implications of the scenarios, in terms of feasibility, are presented. The scenarios must render valuable information to Cryonorm to determine their future strategy, by business opportunities. Scenario A is developed with an autonomous development and is used as reference scenario for the in sequal developed scenarios.

The sequal developed scenarios are developed by finding the opportunities for LNG systems. These opportunities will be found by analysing the causal relation between the aspects out of the framework in chapter 4. This causal relationship is presented in Figure 14, indicated by the black lines. Each of the aspects can positively or negatively contribute to the use of LNG as fuel for inland waterway vessels. In this research, the business opportunities of LNG fuel systems are investigated, henceforth only the aspects that are conceivable to contribute positively to the business opportunities of LNG systems are set out. Out of this opportunity analysis, there are currently four aspects that can cause a positive twist, with some impact, of the use of LNG as fuel. These aspects are coloured and the causal relation to other aspects are shown by size of the coloured lines and positive and negative correlations are indicated.

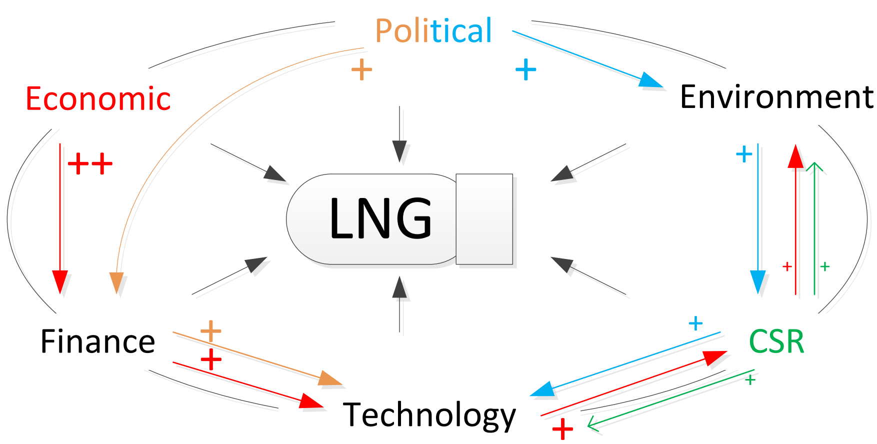

FIGURE 14: CAUSAL RELATIONS BETWEEN ASPECTS (BLACK LINES AND ARROWS) AND CONCEIVABLE OPPORTUNITIES WITH POSITIVE IMPLICATIONS (COLORED ARROWS AND SIGNS, IMPACT BY SIZE)

Since the hypothesis is that there are little business opportunities for using LNG fuel systems for inland waterway vessels, the study was conducted from the point of view of a best case situation. Of note is that, there are very few incentives to move to LNG as fuel for inland shipping companies. Even with this best case situation, there are a few business opportunities of LNG fuel systems for inland waterway vessels. In this chapter, the scenarios are developed by the implications of the four aspects that cause a positively contribution to the use of LNG, hence the first order effects of possible changing aspects are appointed, for the upcoming 10 years. The implications are mainly based on the findings out of chapter 4, some quantified implications are found by research. At last, the implications are analysed and a fleet prognosis is estimated. Besides, threats and opportunities of LNG as fuel in each scenario are discussed.

5.1 Scenario A – Autonomous development

Scenario description

The 'business as usual' scenario is defined by the autonomous developments in the LNG supply chain and the inland shipping market. In the autonomous development, the transition to LNG as fuel is mainly caused by subsidy programs, which is a political aspect, see Figure 12. Subsequently, developments in the LNG supply chain will recruit some launching customers, who are attracted by the Corporate Social Responsibility of using LNG as fuel. Major funds are reserved to boost LNG systems. Until 2020 it is given that is available to move to LNG as fuel by European Union funds. It can be expected that local authorities will provide funds as well. In this autonomous development, it is assumed that equally large funds will continue to exist. This scenario is presented in Table 4, which includes also the implications.

TABLE 4: SCENARIO A - BUSINESS AS USUAL: AUTONOMOUS DEVELOPMENT

Scenario A	**Implications**	
Aspect	*Actor*	
Environment • Emission target of 40% reduction of CO_2.	European Union	• Emission abatements
Economy • Autonomous development • LNG and LSMGO are equal in price, or, no obligation to use LNG as fuel by a subsidy	Exogenous	• Possibly higher freight margins
	LNG supply chain	• Resolving deadlock of LNG supply chain by partly securing customers
Finance • Autonomous development	Banks	• Vision: overcapacity vessels resolved in 2020 (ABN, 2013) • Owner-operators still not financial eligible to invest
	Personal capital	• Very few shipping companies with personal capital and probably unwilling to invest
	Systems suppliers	• Systems become slightly more expensive over the years
Corporate Social Responsibility • Autonomous development	Large companies	• A few large companies, own account operators, will possibly invest in clean energy use for their CSR or green image, such as Heineken or by ports • CSR and deck cleanness of LNG could positively contribute to passenger vessels (excluded from investigation)
Technology • Autonomous development	Engine manufacturers and suppliers	• Reduce methane slip • Improve reliability and maintenance costs
	LNG fuel systems suppliers (Cryonorm)	• Optimization, simple design and improved back office can cause ideal price
Politics • Autonomous development • Mannheim Convention: only subsidies	European Union	• Subsidies for innovation: ○ CEF Transport (Ten-T) ○ European Regional Development

		Fund ○ Cohesion Fund ○ Pre-accession Assistance II ○ European Social Fund (ESF) ○ Horizon 2020
	Local	• Partly resolving deadlock by subsidies • Ports subsidies, innovation subsidies, etc.

Market segments and fleet size

In scenario A, there is still no economic incentive for shipping companies and owner-operators to move to LNG as fuel. Hence, shipping companies and owner-operators will move if the initial investment costs will be covered by subsidies and the use of LNG is not obliged. Incentives by raising taxes are unthinkable, illegal, due to the existence of the legal Mannheim Convention.

Probably, own account operators or long term charter contracts, will cause some vessels to move to LNG as fuel, which will contribute to their Corporate Social Responsibility program.

As set out, there is at least .- available by funds until 2020. Taken into account an initial investment cost of € .- per vessel, it is expected that approximately vessels will move to LNG as fuel in the upcoming 5 years. Besides these available grants, it can be expected that local subsidies become available. Moreover, local authorities can act as a launching customer. The same applies for companies which have an interest in the LNG supply chain, they can request LNG fuelled vessels for their charter contracts.

Fleet prognosis until 2025 in Europe:

- EU subsidized vessels: ± vessels *by funds (extrapolated)*
- Locally subsidized vessels: ± vessels *Including Germany, the Netherlands and Belgium*
- Vessels by CSR or other interests: ≥ vessels *Ports and firms (Launching customers)*
- Cleanliness of LNG: ≥ vessels *Passenger vessels*
- By business case: ± vessels Motor vessels

In this fleet prognosis, the funds are extrapolated until 2025. Although, the aim of subsidizing these vessels is to address shortcomings, resolve obstacles and gain familiarity of using LNG as alternative fuel, is clear. The impact of such subsidization programs is limited (KIM, 5/2015) and a policy changes can stop this subsidization programs and undo its effects.

5.2 Scenario B – NOx Fund

Scenario description

In this scenario, the Norwegian NOx fund is used as an example. By the NOx fund extra taxation, based on the NOx emission, covers initial investments for cleaner shipping. This scenario can only be achieved if the Mannheim Convention is no longer applicable, although legally it is difficult to realise. (KIM, 5/2015) The tax conditions of the Norwegian NOx fund will be used to determine the available funding.

Inland shipping NOx Fund:

- Tax: €2.0 per NOx kg emission (Johnsen, 2013)
- Half of tax income will be used for LNG solutions. (Johnsen, 2013)
- 80% of the initial investment costs will be covered. (Johnsen, 2013)
- Emission factor NOx: 52.7 kg per m^3 LSMGO (Klein, 2012)
- Fuel consumption in Europe: 391,500 m^3 LSMGO (Klein, 2012)
- Total Tax: €27.5 million annually, hence €13.7 million available for LNG.

Market segments and fleet size

Introduction of the NOx fund in inland shipping market in Europe causes the availability of €13.7 million annually for the inland shipping sector to move to LNG. Assuming that all available money will be used, 80% of the initial investment will be covered, and the initial investment is € .- per vessel, it can be expected that vessels annually will move to LNG as fuel each year.

In this scenario it can be expected that approximately vessels will be equipped with LNG fuel systems in the next 10 years, if LNG equals the price of LSMGO or if users are not obliged to use LNG as fuel.

Higher LSMGO prices by tax

A scenario whereby the fuel prices of LSMGO are raised by tax will have the same legal obstacle before it can be introduced, namely the Mannheim Convention. Implications of such scenario, in terms of fleet prospects, are the same for the scenario whereby there is a fuel cost advantage. (See scenario C)

5.3 Scenario C – LNG price advantage

In this scenario, a price advantage of LNG is considered. Outlined in this study is a reference value of the economic potential of LNG as fuel. First, a reference value of , which corresponds with € .- discount on LSMGO per m^3, is used. Taken into account the highest rate of LSMGO of €700.- in 2008, this reference value results into a discount of approximately %.

Second, a price advantage of €/MJ is considered, corresponding with € .- discount on LSMGO per m^3. Taken into account the highest rate of LSMGO, a discount of approximately % is achieved. Moreover, by August 2015, the price of LSMGO was €331.- per m^3.

This scenario is defined by price advantages of LNG for longer times, respectively €/MJ, compared to LSMGO. This price advantage is covered by the economic aspects, as shown in Figure 14. This price advantage causes extra impulses to use LNG as fuel by other aspects, see Figure 14. The implications out of this price advantage are presented by aspect in Table 5.

TABLE 5: SCENARIO C - LNG PRICE ADVANTAGE

Scenario:	**Implications:**	
Aspect	*Actor*	
Environment • None		• External emission costs are excluded • No incentive for emission reduction
Economy • High economic growth	Exogenous LNG supply chain	• LSMGO is expensive • Price advantage LNG is: ○ €/MJ ○ €/MJ • Current interest rates • Supply chain will be more than satisfactory. LNG suppliers securing customers.
Finance • <2020: recovery of crisis • >2020:	Banks Personal capital	• Vision: overcapacity fleet is resolved in 2020 (ABN, 2013) • 25% owner-operators and shipping companies are financial eligible to invest • A number of shipping companies or owner-operators have personal capital and a very few are willing to invest if economical profitable
Corporate Social Responsibility • Little development	Inland shipping	• Inland shipping companies have willingness to invest to use LNG as fuel, which contribute to their Corporate Social Responsibility program • Both investment and earnings of using LNG are for shipping company
Technology • Continual development	Engine manufacturers and suppliers	• Improved reliability and maintenance costs • Improved fuel efficiency

	LNG fuel systems suppliers (Cryonorm)	• Standard prices
Politics • Autonomous development	European Union Local	• Subsidies were available to overcome technological shortcomings, such as efficiency and small scale LNG supply chain. • Facilitation transitions and information sharing

The price advantages are used in the fleet prospects in paragraph 3.4. Thereafter, other vessels are examined by the business case analysis in chapter 3.2. Finally a factor is determined to estimate the fleet. These factors incorporate the implications as presented in chapter 4 and table 5.

Results of Scenario C

First, the fleet prognosis is estimated whereby any obstacles are neglected.

Rijn-Hernekanaalship and Large Rhine Vessel (110m)

A minimum fuel consumption equivalent to m^3 LSMGO is required for both Rijn-Hernekanaalship and Large Rhine Vessel (110m) to potentially economical profitable by an LNG price advantage of €/MJ, see Figure 7. Figure 12 shows that vessels are eligible in the business case analysis to use LNG as fuel, whereby any obstacles are neglected.

At a price advantage of €/MJ, a minimum fuel consumption equivalent to m^3 LSMGO is required. Hence, approximately vessels become eligible to use LNG as fuel.

Large Rhine Vessel (135m), Koppelverbanden (KV), Large Tanker (LT) and Large Container Vessels (LCV)

A minimum fuel consumption equivalent to m^3 LSMGO is required for the motor vessels to potentially economical profitable by an LNG price advantage of €/MJ, see Figure 8. Figure 13 shows that Large Rhine Vessels (135m) are eligible in the business case analysis to use LNG as fuel, whereby any obstacles are neglected. Besides, it can be expected that a substantial part, in terms of %, of the KV, LT and LCV vessels are eligible, by their fuel consumption.

At a price advantage of €/MJ, a minimum fuel consumption equivalent to m^3 LSMGO is required. Figure 13 shows that Large Rhine Vessels (135m) are eligible, whereby any obstacles are neglected. Subsequently, it can be expected that % of the KV, LT and LCV becomes eligible.

The fleet of KV, LT and LCV's consists of approximately 300 vessels. (See chapter 3)

Push vessels

A minimum fuel consumption equivalent to and m^3 LSMGO is required, by respectively an LNG price advantage of and €/MJ, for a business case by push vessels, whereby any obstacles are neglected. Tough, continuous operating push vessels have the highest potential economical profit, the operating profile of such vessels requires high reliability and indirect costs can grow quickly. Hence, shipping companies will be very conservative to move to LNG as fuel. Besides, these push vessels are operated by a limited number of shipping companies (Beelen, 2011) and the total operational fleet size, with more than 1500 kW, is approximately 40 in Europe. (debinnenvaart.nl, 2015)

Movers of eligible motor vessels
In this scenario, such a price advantage of LNG, certainly results in a more resolved deadlock. Hence, some obstacles are resolved and financial situation of shipping companies is improved. Figure 5 shows the implications out of this economical aspect. It is to be expected that there are more movers at higher fuel price advantages. In other words the extent to which the owners of eligible vessels will move to LNG is strongly dependent on the price level. Moreover, increasing or decreasing prices can enhance the move to LNG. The factor to determine the actual fleet prospects in this scenario will therefore carry some uncertainty.

At a LNG price advantage of €/MJ, a factor of for retrofit and a factor of for newly built is assumed. Hence, in this price scenario, it is expected that approximately vessels will be retrofitted with LNG systems until 2020. Subsequently, based on newly built vessels (Vesseldatabase, 2015), it can be expected that approximately newly built vessels will be equipped with an LNG system annually.

At a LNG price advantage of €/MJ, a factor of for retrofit and a factor of for newly built is assumed. Hence, in this price scenario, it is expected that approximately vessels will be retrofitted with LNG systems until 2020. Subsequently, based on newly built vessels (Vesseldatabase, 2015), it can be expected that approximately newly built vessels will be equipped with an LNG systems annually.

Movers of eligible push vessels
Concerning push vessels, the market are severed by a limited number of large companies. They will heed to opportunities to make more profit, despite the fact that they are conservative. It can be expected, that just one push vessel will be retrofitted with an LNG system for testing and experience. Successful experiences can cause a major transition of this fleet, but this can only be expected after testing.

Fleet prognosis until 2025
Fleet prognosis, 0.006 €/MJ, until 2025:

- RHK and LRV (110m): ± *Retrofit*
- LRV (135m) ± *Retrofit*
- KV, LT and LCV ± *Retrofit*
- Push Vessels: ≥ *All or nothing*
- RHK and LRV (110m): ≥ *Newly built*
- LRV (135m), KV, LT and LCV: ± *Newly built*

This results in approximately inland waterway vessels, which will be equipped with LNG systems until 2025.

Fleet prognosis, 0.01 €/MJ:

- RHK and LRV (110m): ± *Retrofit*
- LRV (135m) ± *Retrofit*
- KV, LT and LCV ± *Retrofit*
- Push Vessels: ≥ *All or nothing*
- RHK and LRV (110m): ≥ *Newly built*
- LRV (135m), KV, LT and LCV: ± *Newly built*

This results in approximately inland waterway vessels, which will be equipped with LNG systems until 2025.

5.4 Business opportunities for LNG fuel systems

In this paragraph, the scenarios and their implications are analysed. From this, valuable information is rendered to determine the business opportunities of LNG fuel systems for Cryonorm.

Analysis of the scenarios and their implications

Movers to LNG as fuel

Business opportunities for LNG fuel systems

In this paragraph, the business opportunities for LNG fuel systems for Cryonorm are rendered. The business opportunities presented have the aim to add value to the business of Cryonorm.

Figure 3

6 CONCLUSIONS AND RECOMMONDATIONS

In this chapter, the data obtained during this study is analysed, interpreted and discussed. First, the conclusions of the potential economic profitability of using LNG as fuel for inland waterway vessels are presented. Second, recommendations for Cryonorm are discussed by answering the research question.

This chapter must be read in the sequal of section 1.1.7, whereby conclusions out of the preliminary research are presented.

6.1 Conclusions

Business cases for LNG fuelled inland waterway vessels are mainly defined by 3 aspects, which will mainly alter the total costs of shipping, namely:

- Fuel consumption
- Price advantage of using LNG as fuel opposite to LSMGO
- Capital costs of required investment

As long as using low sulphur marine gas oil (LSMGO) is cheaper than LNG, there is no business case, by the nonexistence of other incentives.

Considering the best case situation for using LNG as fuel for inland waterway vessels, the business case of using LNG as fuel starts with LNG price advantage of approximately €   .- per m^3 LSMGO for motor vessels, with a length of ≥85 m.

For the main part of the fleet it can be considered that larger motor vessels are more eligible, based on the main characteristics of the fleet, to potential use LNG as fuel. On the other hand, the total fleet of the Rijn-Hernekanaalschip and Large Rhine Vessels (95 – 135m, mainly 110m) is enormous. Hence, the absolute number of eligible vessels to potentially move to LNG as fuel by these considered vessels is larger. Out of this, it can be expected that if some Rijn-Hernekanaalship and Large Rhine Vessels become eligible to use LNG as fuel, they will rather be retrofitted with an LNG fuel system, due to the low share of vessels that consumes enough.

The highest conceivable annual fuel consumption of vessels, shown in paragraph 2.1, is representative for a very few vessels in the fleet. Therefore, it can be assumed that a few Koppelverbanden, Large Tankers and Large Container Vessels get eligible more quickly to use LNG as fuel. Though, the current fleet of such motor vessels is small.

Fuel consumption of the inland vessels is typically quite low (MoVe IT!, 2014), compared to seagoing vessels, therefore the potential benefits using LNG are much less. (MoVe IT!, 2014) Hence, a financial viable modernization option to reduce fuel costs is difficult. Hence, only a few vessels with high fuel consumption become potentially eligible to use LNG.

Concerning push vessels, the market are severed by a limited number of large companies. They will heed to opportunities to make more profit, despite the fact that they are conservative. Push vessels are the most eligible, in terms of a potential business case, to move to LNG as fuel. Tough, the fleet is very small.

The business cases were conducted out of a best case situation, whereby any obstacles of using LNG were neglected.

6.2 Recommendations for Cryonorm

This paragraph shows recommendations for Cryonorm. Hence, the research question is answered.

DEFINITIONS

Barriers	Barriers are negative factors or challenges for shipping companies to move to LNG as marine fuel. (Push factors)
Bunkering	Bunkering means refuelling a ship
Business Case	Business Case is defined as the consideration between costs and financial benefits of LNG as marine fuel for inland waterways vessels. Herein OpEx and CapEx
Business Model	Business Model is in broad sense all aspects and subsystems related to LNG as fuel for inland waterways vessels. Herein includes the business case and factors.
Chicken Egg Dilemma	Chicken Egg Dilemma – "Who will act first?" that's the classic Chicken Egg Dilemma. See at definition deadlock
Cryonorm	Cryonorm means Cryonorm Systems BV, unless is stated otherwise in this report.
Deadlock	Deadlock "Owners will not start using new fuels if an infrastructure is not available, and energy providers will not finance expensive infrastructure without first securing customers.
Dual Fuel Engines	Dual Fuel Engines are engines that run on diesels or on a mixture of natural gas and diesels.
Drivers	Drivers – driving forces; positives factor for shipping companies to move to LNG as marine fuel. (Pull factors)
Essential barriers	Essential barriers – Push factors needed for success of the business case/model.
Liquefied Natural Gas	LNG - Liquefied Natural Gas: Natural gas is a gas mixture containing predominantly hydrocarbon gases, which mainly consists out of methane. Natural gas is a clean fossil fuel with low carbon dioxide emission, equivalents, compared to conventional fossil fuels. Natural gas can be liquefied (LNG) to have a higher energy density on both volume and weight, consequently comparable, in the same order of magnitude, with diesels. LNG is cryogenic at a temperature of approximately -162° Celsius. (Linde, 2009)
LNG systems	LNG systems means systems made by Cryonorm to provide ships with equipment to sail on LNG
LNGpac	LNGpac – LNG systems for dual fuel engines of Wärtsilä in vessels, developed in in co-operation with Wärtsilä.
Market size	Market size means the magnitude of number of ships (fleet) whereby the business model is feasible, weighed against the existing fleet. In case of scenarios the market size is corrected by scenarios.
Shipping companies	Shipping companies includes the perspective from ship owners and operators
First Mover Advantage	The ability of pioneers to earn positive economic benefits out of new resources or technology. In this case the pioneers who use LNG as fuel for IWW vessels. Oposite are first mover disadvantages (FMD)
Spare Fuel	Spare Fuel is extra LNG required in case of a full-gas configuration, due incipient infrastructure of LNG.
Koppelverband	Push boat with barge

ABBREVIATIONS AND ACRONYMS

ADN	European agreement concerning the international carriage of dangerous goods by inland waterways
BV	Bureau Veritas (Class society IACS)
CapEx	Capital Expenditures
CCNR	Central Commission for Navigation on the Rhine
CEMT	Classification of European Inland Waterways
CNG	Compressed Natural Gas
DF	Dual Fuel, see Dual Fuel Engines
DNV GL	Det Norske Veritas Germanischer Lloyd. DNV and GL are merged in 2013. (Class society IACS)
EC	European Committee
ECA's	Emission Control Area's, which is defined by the MARPOL of the IMO
FMA	First Mover Advantages
HAZID	Hazard Identification
HFO	Heavy Fuel Oil is a heavy residual fuel, needs heating for viscosity in engines
IACS	International Association Classification Societies
ICIS	ICIS is the world's largest petrochemical market information provider and has fast-growing energy and fertilizer divisions.
IGC code	The international code for the construction and equipment of ships carrying liquefied gases in bulk (by IMO)
IGF draft	The draft international code of safety for ships using gases or other low flashpoint fuels (by IMO, not mandatory)
IMO	International Maritime Organisation
IP	Interconnection piping
ISO	International Standards Organisation
ISO 14001	Environmental management standards to help organizations (will be replaced by ISO 9001:2015 in September 2015)
IWW	Inland Waterways
KV	Koppelverbanden, Push barge with barge
LNG	Liquefied Natural Gas
LR	Lloyds Register (Class Society - IACS)
LSFO	Low Sulphur (Heavy) Fuel Oil
LCV	Large Container Vessel
LRV	Large Rhine Vessel
LT	Large Tanker
MARPOL	International convention for the prevention of pollution from ships
MDO	Marine Diesel Oil is a mixture of HFO and distillates, sometimes called MFO (marine fuel oil)
LSMGO	Low Sulphur Marine Gas Oil is a diesel made from a distillate only
MJ	Mega Joule
MSC.285(86)	Interim guidelines on safety for natural gas fuelled engine installations in ships (by IMO, mandatory)
mts	Motortankership

NOx	Nitrogen Oxides (NO, NO2)
OpEx	Operational Expenditures
PM_{10}	Particulate Matter of 10 micron
PTS	Pipeline/terminal to Ship
ROI	Return on investment
RVIR	Rhine Vessel Inspection Regulations (mandatory)
SECA’s	Sulphur Emission Control Area’s, addition to ECA’s, which is defined by the MARPOL of the IMO
SOLAS	The international convention for the safety of life at sea (by IMO)
SOx	Sulphuric Oxides (SO, SO2, SO3, SO4)
STS	Ship to Ship bunkering
TCS	Tank Connection Space
TEU	Container: Twenty feet Equivalent Unit
TTF	"The Title Transfer Facility (TTF) is a virtual market place where we offer market parties the opportunity to transfer gas that is already present in our system (‘entry-paid gas’) to another party."(gasunie)
TTS	Truck to Ship bunkering
VAT	Value Added Tax

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APPENDIX A: ECONOMIC POTENTIAL OF LNG AS TRANSPORT FUEL

LNG as marine fuel for IWW is used more and more. LNG as fuel has an environmental driver, but the economic potential is key for shipping companies to move to LNG as fuel. In this appendix the LNG price in the Netherlands is investigated, though deep market understanding of LNG pricing is scoped out of this research.

In this research, prices of fuel are compared on their energy density according to the values in Table 6.

TABLE 6: FUEL CONDITIONS AND PROPERTIES (E.BUTHKER, 2015)

Fuel	Energy (1)		Energy (2)		Density	
CNG	38	MJ/kg	31.65	MJ/m3	0.833	kg/m3
LNG	49	MJ/kg	22	MJ/liter	0.45	kg/liter @ -160 C
Diesel	42	MJ/kg	36	MJ/liter	0.84	kg/liter @ 15 C

LNG as truck fuel, prices today

LNG is commercially available for trucks by several LNG gas stations in the Netherlands. In front of CNG, LNG is not free of excise duty, though it has favourable VAT share compared to diesel, until 2018 there's a limited return on this excise duty of €0,125 of the total €0,33 per kg LNG. Opposite to the excise duty of €0,48 per litre of diesel. (MvF, 2015) The price advantage of LNG for truck, compared to diesel, has fluctuated between 30% and 43% in the past 3 years, see Figure 15. It should be observed that comparisons between diesel and LNG prices commonly are based on €/liter diesel versus €/kg LNG, but this is undesirable. Euro per Mega Joule (€/MJ) is considered for price benchmarking between LNG and MGO or diesel in this research.

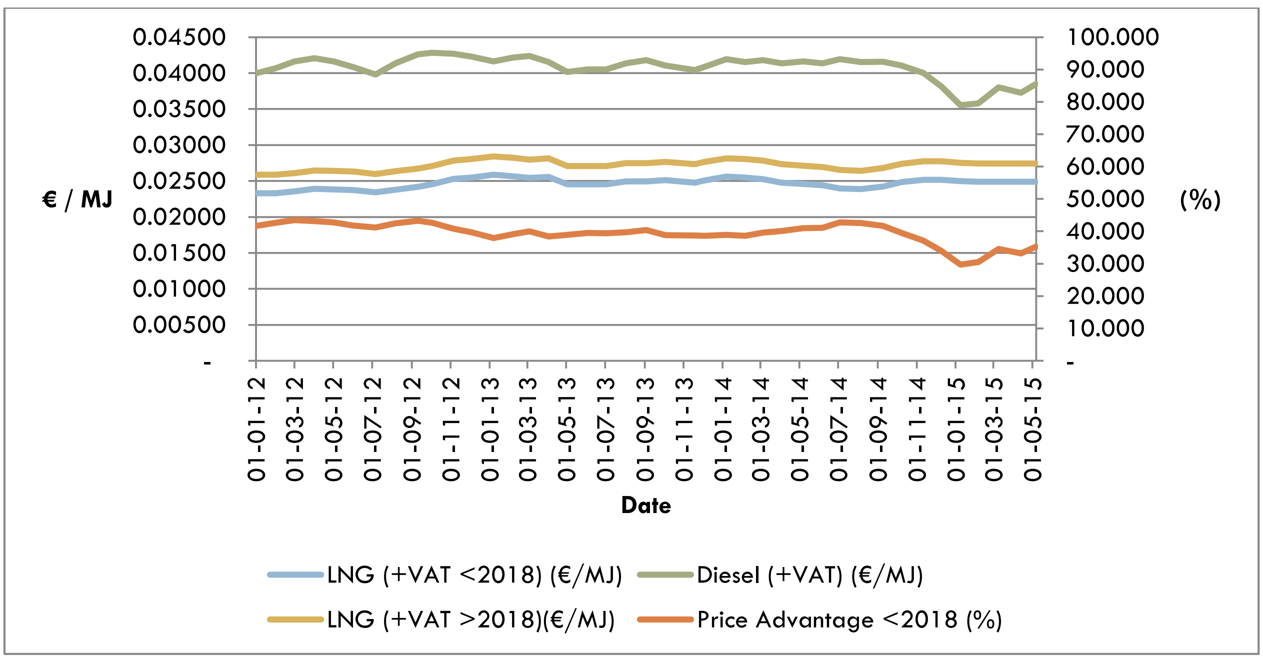


FIGURE 15: LNG PRICING COMPARED TO DIESEL OWN COMPOSITION, SOURCES: (MVF, 2015) (LNG24, 2015)

LNG as fuel for vessels, bunkering prices today

In the Netherlands several market players offer LNG, for example: Primagaz, Linde gas and LNG24. The current offered LNG contracts and bunker prices are varied and kept quiet. (Sund; Whitefield, 2014) (Slooff, 2015) LNG is bunkered by trucks for IWW vessels to date, also known as Truck to Ship (TTS). Pipeline/Terminal to Ship (PTS) can be expected operational by the break bulk terminal on the Maasvlakte in the fourth quarter of 2016, and more inland satellite terminals will probably follow coming years. (Boktor, 2015) (Hof, 2015) (LNG-platform)

Though LNG bunker prices are kept quit, some market players offer prices:

> "The price of LNG (bunkered in the ship) varies between € and € /ton. This price depends on the LNG market price and bunker location." (E.Buthker, p. 1)
>
> Primagaz offers LNG also by truck, by a full load, its € /tonne kg LNG. (Slooff, 2015)

The price of LSMGO is dependent on two factors; price of LSMGO and the Dollar/Euro exchange rate. Figure 16 shows a graph whereby the LNG bunker prices and LSMGO bunker prices are fitted to each other on Euro per Mega Joule. The price difference of LNG, by the lowest known bunker price in the Netherlands, varies between % to % last year. The price disadvantage of LNG past half year is validated by Anthony Veder, they stopped using LNG as fuel for their dual fuelled vessels for now. (Tel, 2015)

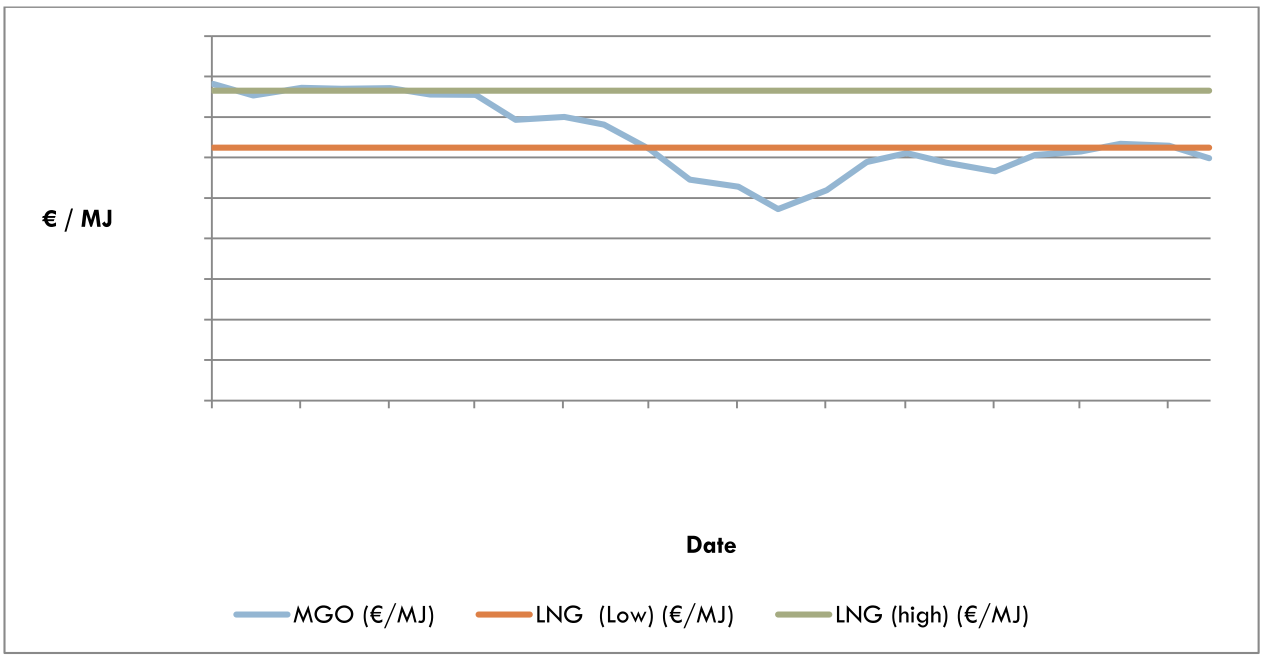


FIGURE 16: BUNKER PRICES LNG AND MGO. SOURCES: (SHIPANDBUNKER, 2015) (ECB, 2015) (BUTHKER) (E.BUTHKER, 2015) (SLOOFF, 2015)

Economic Potential of LNG

Though LNG was not beneficial last year, the economic potential of LNG is probably more important. To understand the economic potential, underlying market circumstances are explored, by using the full-picture perspective, see Figure 17. (Sund; Whitefield, 2014)

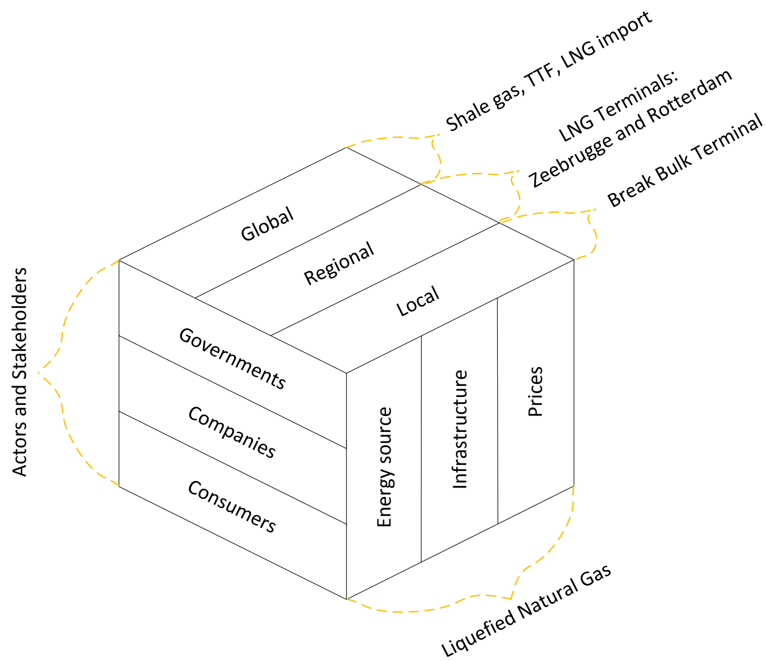


FIGURE 17: FULL-PICTURE PERSPECTIVE FIGURE BASED ON SOURCE: (SUND; WHITEFIELD, 2014)

Natural gas is requisite to make LNG, this process will cost energy; 8 to 10 percent of the gas. (Total, 2015) Though this high inefficiency to produce LNG, it outweighs the transport abilities to balance supply and demand of the gas market globally, which is called the large scale LNG market. Preconditions for this global trade are differences in gas prices and LNG export and import terminals. Wholesale of LNG could eventually act as an equalizer of world gas market prices. (Sund; Whitefield, 2014)

Favourable gas prices in Australia and the shale gas extraction in the United States have resulted in developments of LNG export terminals at those places. (Wentink, 2015) Focused on the North Sea region two import Terminals are under construction; the Gate Terminal on the Maasvlakte and the LNG-Zeebrugge Terminal in Belgian. These LNG import terminal has great capacity to ensure energy security in Europe, due to the uncertain gas delivery by Russia. (Zijverden, 2015) Large scale regasification of LNG by these terminals can provide the existing Europe's gas hub with natural gas. These LNG terminals gave the opportunity to use LNG commercially; therefor the break bulk terminal is currently under construction at the Maasvlakte. The import capacity of LNG is still growing in Europe, eventually to ensure countries energy independency. Subsequently the LNG export market is growing rapidly in the United Stated and Australian, due to price difference in gas, see Figure 18.

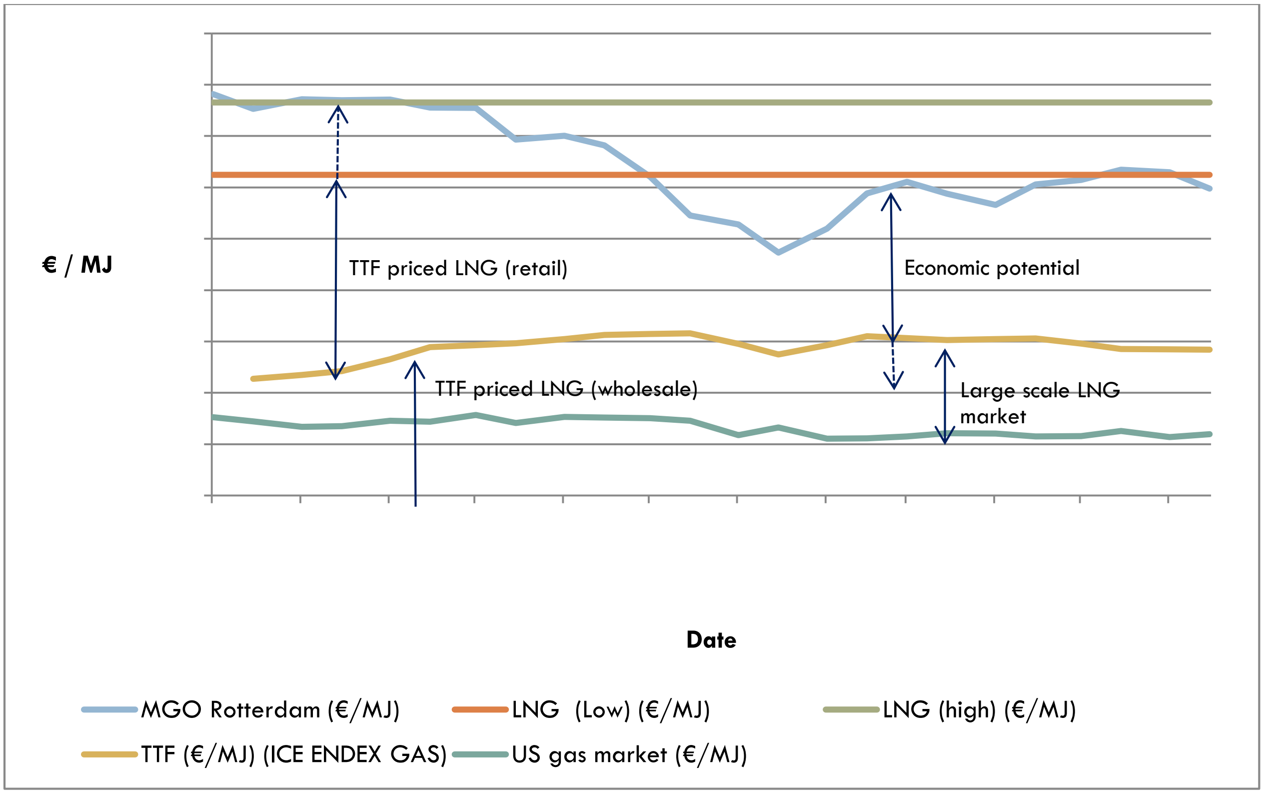


FIGURE 18: LNG PRICE ANALYSIS
SOURCES: (BUTHKER) (E.BUTHKER, 2015) (SHIPANDBUNKER, 2015) (ECB, 2015) (SLOOFF, 2015) (TTFGAS, 2014-2015) (INFOMINE, 2015)

The economic potential of LNG as marine fuel is two folded. For one thing the LNG wholesale price, secondly the difference between the wholesale and retail price.

It is likely that LNG will be oversupplied by Australian, North America, Russia and East Africa to the LNG terminals in Europe. This large scale LNG transport is intended, by regasification, to provide the European gas hub with cheaper gas. On the other hand this LNG could directly be used by small scale LNG consumers. It can therefore be believed that the natural gas hub prices, TTF in the Netherlands, equals the LNG wholesale prices in Europe. The costs for liquefaction are part of the large scale LNG market, if and only if LNG will be imported by the terminals in Europe. See Figure 18 for an LNG analysis of the large scale LNG market and wholescale.

The difference between wholesale and retail prices are significant for LNG, which is opposite to oil based fuels. (Sund; Whitefield, 2014) Currently, there is a small market for small scale LNG and there are only a few small scale LNG suppliers in the Netherlands and its hinterland. As shown in Figure 18 there are high margins on the retail price of LNG, which could even be higher by increased MGO prices. Though most LNG contracts are kept quiet, some consumers have contracts, made in the past, with LNG suppliers with a guaranteed percentage of advantage, which is linked to LSMGO. (Tel, 2015) Subsequently, more competition by the LNG suppliers can be expected if the deadlock is resolved. More competition will eventually result in lower margins on the LNG retail price.

LNG could be the cheapest marine fuel and has therefor the economic potential in extant, up to % by today's prices. Nevertheless there are a lot of uncertainties involved by the development of the LNG supply chain, and therefore it's pricing, besides the uncertainties of the Dollar-Euro rate, oil prices and emission regulations.

APPENDIX B: VESSELS AND THEIR FUEL CONSUMPTION

In this appendix, requirements for LNG fuel systems and use of LNG as fuel for vessels is investigated. The requirements of LNG fuel systems, and therefore design and costs, are different for each type of vessel, propulsion system and its usage. First, operational parameters, such as annual fuel consumption and operational hours, are estimated by a typical trading pattern, Rotterdam – Koblenz, for each vessel. Although this trading pattern is representative for a large share of IWW transport in Europe, these parameters are analysed by parameters from literature.

Types of IWW vessels and their fuel consumption

This section shows the type of IWW vessels for which the LNG fuel systems of Cryonorm are applicable. IWW vessels, class size of IV or greater, are considered, due to constraints on installation space by rules and regulations of the CCNR and Class societies. (CCNR, 2014) (LR, 2012)

IWW vessels in Europe are classified by the Conférence Européenne des Ministres de Transport (CEMT). Generally these CEMT classes correspond to the navigability of waterways, but there is also a correlation to their deadweight tonnage (dwt).

Per type of vessel specifications and typical parameters, which are applicable and useful for this investigation are presented. Typical parameters, such as current fuel consumption numbers, are gathered by literature study and interviews and presented by an own compositions. Considered is a typical roundtrip of Rotterdam - Koblenz – Rotterdam, by navigation over the Waal and Rhine. Distinction is made for different type of vessels, namely tankers, dry-bulk and container vessels.

CEMT Classes, Owners and Capacity

Table 7 shows the CEMT classes of IWW vessels and their characteristics, which are set out in the scope of reaearch . On the Rhine, from Rotterdam to Germany, it is predominantly navigated by motor vessels (66%; including motor vessels of a Koppelverband) and pushed convoys, a pusher with lighters. (EICB, ~2011) The push convoys, with 2, 4 or 6 lighters navigate upstream, opposite to downstream, with a different layout. As assumed, these types of vessels will be analysed on a trading pattern from Rotterdam to Koblenz, though due to constraint waterway class size the push convoy CEMT VIc, 6-bakduwstel, is constraint to Rotterdam – Duisberg. In the second column of Table 7 the vessels' dimensions are presented, accompanied by their tonnage. This tonnage is based on their typical draught, constraint to the waterways. For this research a draught of 3.5 meters is considered for the calculations for all types of vessels, because this typical trading pattern is considered. It should be noted that not every CEMT class IV vessel can possible reach a draught of 3.5 meter. On the other hand, the draught for the larger vessels is reduced for calculations.

In the third column of Table 7 calculations are performed to determine the maximum deadweight tonnage of every type of vessel within this scope of research. To eventually estimate the vessels parameters, whereby dry-bulk transport is considered. In contrast to road transport, the IWW vessels have a lifetime of more than 25 years. The IWW vessels can be owned by an owner-operator, own account operators or shipping companies. Owners-operators are the owners and operators of the vessel, commonly a family, and in case of a vessel larger than a Rijn-Hernekanaalship they are commonly accompanied with relatives. Own account operators are mainly industrial companies with large volumes of products, such as Heineken in Zoeterwoude. On the other hand, shipping companies are owners with multiple vessels and carry out transport for others. (Beelen, 2011)

TABLE 7: CLASSIFICATION AND CAPACITY OF IWW VESSELS AND PUSHED CONVOYS

		From literature				Calculations for research			
CEMT Class	**Name**	**Tonnage [t kg]**	**Length [m]**	**Breadth [m]**	**Draught [m]**	**Calculated Deplacement [m³]**	**Calculated Max Weight Vessel [ton kg]**	**Calculated Displacement by 3.5 m draught [m³]**	**Calculated Max Deadweight (ton kg)**
IV	Rijn-Hernekanaalship (Europaschip)	1350	85	9.5	2.5	2019	669	2826	2158
Va	Large Rhine Vessel (110m)	2750	110	11.4	3	3762	1012	4389	3377
Vb	Large Rhine Vessel (135m)	4000	135	11.4	3.5	5387	1387	5387	4000
Vb	Large Tanker	9500	135	21.8	4.4	12949	3449	10301	6851
VIb	Koppelverband	6000	185	11.4	3.5	7382	1382	7382	6000
VIa	2-bakduwstel (push convoy)	5500	172	11.4	4	7843	2343	6863	4520
VIb	4-bakduwstel	11000	193	22.8	4	17602	6602	15401	8800
VIc	6-bakduwstel	16500	193	34.2	4	26402	9902	23102	13200

Source: own composition (Binnenvaart, 2015) (Via-Donau, 2007)

IWW vessels are predominately owned by owners-operators in Europe, the considered motor vessels and Koppelverbanden in this investigation are more evenly distributed, due to their large size and more continuous operating profile. Push convoys, push vessels with lighters, are predominately owned by a limited number of large companies, especially the ones with 4 or 6 lighters in continuous operation.

Fleet characteristics

The main characteristics per type of vessel are presented in this section.

CEMT IV: Rijn-Hernekanaalschip (Europe Vessel)

These types of vessels are characterized by a vessels length of 80 to 85 meter and a maximum beam of 9.5 meters. Although a trading pattern from Rotterdam till Koblenz is considered a CEMT IV vessel is capable to navigate to northern part of Germany. (Via-Donau, 2007) Generally a vessel with a lower CEMT classification can access more waterways. These vessels have one engine with a power of 870 kW, on average. (Vesseldatabase, 2015) This type of vessel is predominately owned by owners-operators. They often serve the sport market or they are in a time charter for a shipping company or terminal operator. The difference between serving the spot market or in a time charter can drastically change parameters, such as fuel consumption, by approximately by 60%. (Beelen, 2011)

CEMT Va & Vb: Large Rhine Vessel (LRV) and Large Tanker

The Large Rhine Vessel (LRV) is the most operated type of vessels considered in this study. LRVs are characterized by a vessels length of 95 to 135 meters, mainly 110 meters and a beam of 11.5 meters, sometimes slightly more. LRV (≤110m) are commonly equipped with one engine with a power of approximately 1350 kW. The 135 meter long Large Rhine Vessels are equipped with 2 engines, sometimes 3 in case of a Large Tanker, or related Large Container Vessel.

A typical LRV (≤110m) is typically owned by an owner-operator, accompanied with and relative, for example two families. This structure makes it possible to operate the vessel unto 24 hours a day. These types of IWW vessels can in example navigate to the Danube. There are approximately 700 LRV vessels with a length of 110 meter in operation these days. (debinnenvaart.nl, 2015)

LRV with a length of 135 meters, commonly wider also, are often more dedicated to their cargo, these vessels are in example less flexible. LRVs with a beam wider than 11.5 meters are typically owned by a shipping company on serve on time charter. These types of vessels are relative new as for inland shipping over the Rhine. There is a range within the width of the vessels and therefor the deadweight and required power from the engines. The smallest vessels, approximately 15 meters breadth, have a minimum of a total propulsion power of 2000kW, but is must be considered that these newly built vessels are already fuel efficient.

The flexibility of these types of vessels is more limited to:

- Changing cargo from dry-bulk to containers or vice versa.
- Trading pattern is more limited by waterway class.
- Transhipment terminals must be suitable for wider and larger IWW vessels, port times can affect productivity. Hence, fuel consumption.

CEMT Vb: Koppelverband

The Koppelverband is commonly a shortened LRV, therewith identical on structure and use, with a straight bow with one barge in front, push barge vessel with a barge in front. Commonly, a Koppelverband has total length of 178 meters. This type of vessel is commonly equipped with two engines with a total power of approximately 1800 kW. A Koppelverband has advantages on flexibility and layout configuration of the barge, which can be linked sideways. For this research Koppelverbanden of only this size are considered, if Koppelverbanden use more than just one barge, it is considered as a push convoy. Approximately 200 Koppelverbanden are in operation these days. (debinnenvaart.nl, 2015) Newly built Koppelverbanden are already fuel efficient, in contrast to older Koppelverbanden. Hence, older Koppelverbanden could be a good case to potentially save fuel costs.

CEMT VI: Push Convoys

Push convoys consist out of a push vessel and one or more non-propelled pushed lighters, also called barges. Different CEMT classes belong to different configurations, see Table 7. A limited number of large shipping companies own all larger push convoys. Push convoys are operated 24 hours a day and are operated by staff. The parameters, such as fuel consumption, for the different sizes of push convoys are expected to be different.

Push vessels can have up to 4200 kWh power, produced by 2,3 or even 4 engines. In this study, only push vessels with at least 1450 kWh power are considered. In case of an LNG fuel system, these push vessels are the smallest vessels, though they have the most machinery. There are approximately 40 push convoys with more than 1450 kWh in operation in Europe. (debinnenvaart.nl, 2015)

Push convoys navigate often between Amsterdam – Rotterdam – Antwerp and the considered trading pattern, within the scope of research. As remarked a push convoy with 6 lighters can navigate till Duisburg.

Roundtrip: Rotterdam – Koblenz and Fuel Consumption
To estimate the vessels' fuel consumption a roundtrip from Rotterdam – Koblenz is considered.

Fuel consumption roundtrip

The considered roundtrip, Rotterdam to Koblenz, has a length of 810 km in total, navigation over the Waal and Rhine. On this waterway no locks or other time taking barriers are presented. From Rotterdam to Duisburg the waterway class is suitable for all considered vessels, though from Duisburg to Koblenz the waterway class is lowered to CEMT VIb, therefor a push convoy configuration with 6 lighters, 6-duwbakstel, is considered to have a trading pattern till Duisburg, which is 217 km from Rotterdam.

In the second column in Table 8, parameters for fuel consumption calculations are assumed. Though fuel consumption can be influenced by many parameters, such as water depth, vessels speed and design speed, water flow, water depth, draught & design draught, vessels beam, vessels length and keel clearance. For this investigation, estimation of LSMGO use is conducted by using numbers based on current practices (EVO-gasolieverbruik, 2011) Within the studies for fuel consumption the travel speeds of the vessels are assumed, which correspond to the assumption of fuel consumption, see second column in Table 8. Important to know is that vessels fuel consumption is heavily influenced by its speed, increase of speed requires engine power, by powers of three, which is a rule of thumb. (EVO-gasolieverbruik, 2011) Besides, it is assumed that the vessels are loaded upstream and unloaded downstream.

In the third column of Table 8, the fuel consumption and travel time for a roundtrip, in terms of m^3 LSMGO, are estimated. Though, parameters to define the fuel consumption are based on best practices it could therefore be representative and useful for the continuation of this study. On the other hand, consideration of this roundtrip could not be representative for all types of vessels compared to their actual trading pattern. It could be imagined that higher CEMT classes correspond better with the assumed trading pattern. Moreover, it can be expected that motor vessels, among the considered motor vessels, have different fuel efficiency. Subsequently, newly built Koppelverbanden could be expected more fuel efficient.

Calculated annual fuel consumption by roundtrip

Annual full consumption per type of vessels is mostly dependent on the total distance of navigation annually. For this calculation, the roundtrip is considered and operational parameters are assumed by literature data: (Beelen, 2011) As well as port times and waiting times: (Via-Donau, 2007) (Beelen, 2011). These parameters can heavily influence the annual total distance of navigation annually, see table 9.

Typical parameters, such as operational hours per day, fuel consumption etc, are figured out per type of ship on a trading pattern from Rotterdam to Koblenz, in case of a CEMT VIc push convoy till Duisburg. (Via-Donau, 2007)

The second column of Table 9, shows the assumed parameters. The port times are dependent on three aspects, (un)loading capacity, terminal operation hours and port waiting times, such as a notification day to get new freights. Secondly, the vessels operational hours, operational days are assumed. The third column in Table 9 shows estimations of annual fuel consumption based on the roundtrip and operational parameters. These operational parameters are assumed on their typical ownership and the type of market they serve.

TABLE 8: FUEL CONSUMPTION ROUNDTRIP: ROTTERDAM – KOBLENZ (DUISBERG)

		Literature					Calculations	
CEMT Class	**Name**	**Fuel consumption (Mean-upstream) [Litre/ton-km]**	**Fuel consumption (Mean-downstream) [Litre/ton-km]**	**Speed upstream [km/h]**	**Speed downstream [km/h]**	**Distance roundtrip: R'dam – Koblenz – R'dam VIc: to Duisburg [km]**	**Fuel consumption roundtrip [m³ MGO]**	**Total travel time [hours]**
IV	Rijn-Hernekanaalship (Europaschip)	5.5	3.3	14	20	810	5.7	49
Va	Large Rhine Vessel (110m)	5.5	3.3	14	20	810	8.9	49
Vb	Large Rhine Vessel (135m)	5.5	3.3	14	20	810	10.8	49
Vb	Large Tanker	5.5	3.3	14	20	810	19.9	49
VIb	Koppelverband	6	3.5	12	19	810	16.5	55
VIa	2-bakduwstel (push convoy)	3.7	1.7	9	17	810	8.4	69
VIb	4-bakduwstel	3.7	1.7	9	17	810	17.7	69
VIc[1]	6-bakduwstel	3.7	1.7	9	17	434[1]	14.3[1]	37[1]

[1]constraint trading pattern due waterway class; Rotterdam - Duisburg

Source: own composition (Binnenvaart, 2015) (Beelen, 2011) (Via-Donau, 2007) (EVO-gasolieverbruik, 2011)

TABLE 9: OPERATIONAL PARAMETERS AND ANNUAL ROUNDTRIP CALCULATIONS

		From literature Assumed parameters					Calculations for research		
CEMT Class	**Name**	**Bulk loading per vessel/lighter [t/hour]**	**Bulk unloading per vessel/lighter [t/hour]**	**Sailing hours a day [hours]**	**Annual operational [days]**	**Port waiting times per loading [days]**[1]	**Roundtrip in days**	**Annual no. of roundtrips**	**Annual fuel consumption [m³ MGO]**
IV	Rijn-Hernekanaalship (Europaschip)	150	100	14	280	1.5	6.5	43	245
Va	Large Rhine Vessel (110m)	150	100	18	280	1	6.1	46	409
Vb	Large Rhine Vessel (135m)	150	100	18	280	1	6.5	43	463
Vb	Large Tanker	150	100	18	320	0.75	8.2	39	772
VIb	Koppelverband	150	100	18	320	0.75	5.9	54	898
VIa	2-bakduwstel (push convoy)	150	100	24	320	0.75	5.2	62	517
VIb	4-bakduwstel	150	100	24	350	0.5	4.9	71	1268
VIc	6-bakduwstel	150	100	24	350	0.5	3.6	98	1399

[1]These numbers are assumed by an educated guess based on the numbers provided by literature

Source: own composition (Binnenvaart, 2015) (Beelen, 2011) (Via-Donau, 2007) (EVO-gasolieverbruik, 2011)

The annual number of roundtrips, as shown in the third column of Table 9, shows that it can be strongly influenced by the operational parameters, such as annual operational days and sailing hours a day.

Annual fuel consumption

The third column of Table 9, shows the calculated annual fuel consumption per type of vessels on the specified trading pattern. As remarked, the operational parameters are from strong influence on the annual fuel consumption, rather less than the fuel efficiency of the vessel itself. This typical trading pattern is considered, due to the deadlock of the LNG supply chain and the large transport flows on this trading pattern. Though, the annual fuel consumption values are analysed by comparison. This comparison data is gathered by literature study and interviews.

Figure 19 shows the calculated annual fuel consumption compared to annual fuel consumption out of literature, for motor vessels. All calculated annual fuel consumption values are considerable higher. Per type of vessels the possible reasons of this higher fuel consumption are pointed out.

Rijn-Hernekanaalship

The calculated annual fuel consumption is 3 times higher than data of the annual fuel consumption out of literature. As remarked this type of vessel is typically owned by his operator, consequence is that the operational parameter, trading pattern and navigation speed is probably not representative. As the name and CEMT class suggest, this type of vessel can navigate on smaller waterways, with possibly locks and bridges, with waiting times as result. Subsequently, is thinkable that owner-operators navigate with lower speeds to save fuel. The calculation was performed with a draught of 3.5, which is 40% higher than the design draught of the vessel. At last, the owner-operators are predominately serving the spot market, which can influence the waiting times, therefore less roundtrip annually. Besides, these aspects the terminal waiting times can be significant higher, especially for smaller terminals, which can be served by these smaller vessels. All these aspects are part of the vessels productivity. In contrast to the assumed (un)loading times its common practice to have 2 days (Beelen, 2011) waiting time by each port visit.

Large Rhine Vessel (LRV)

The calculated data is more than twice the data found by literature. For all considered type of IWW vessels the LRV is the most used type in this investigation. At the same time there is a more equal distribution of possible ownerships and the market served. The possible aspects which influence the vessels productivity, will match with the findings for the Rijn-Hernekanaalship, but in some lesser extent.

Large Tanker

The calculated data for the Large Tanker, and therefor also its comparable Large Container Vessel, is 23% higher than the literature source. Different operational parameters can easily influence the fuel consumption to this lower value. This type of vessel are predominately chartered, therefore the vessels productivity is higher and match better with the assumed trading pattern and operational aspects. On the other hand, the used deadweight tonnage is lowered compared to the vessels capacity.

Koppelverbanden

The calculated value of annual fuel consumption of the Koppelverbanden is slightly lower compared to the data from literate. Operational parameters used are comparable with the operational parameter used by the EICB. The considered Koppelverbanden are often LRV with a barge in front. The flexibility of Koppelverbanden results probably in higher operational parameters, compared to LRVs. The total considered fleet, operational in Europe of Koppelverbanden, is approximately 150, which is small. (debinnenvaart.nl, 2015) Notable is the difference of annual fuel consumption calculated between the Koppelverband and 2-bakduwstel. The considered fuel consumption, by EVO, per [l/ton km] differs from 60% upstream to 100% downstream. (EVO-gasolieverbruik, 2011)

Push Convoys

Annual fuel consumption of the push vessels is heavily dependent on the operational parameters and the number of lighters. The calculated data for push convoy with six lighters in front, 6-bakduwstel, is less than half of the fuel consumption of the Veerhaven X. The difference is due to the short port and waiting time of the Veerhaven X, it only stays 1.5 hours in Rotterdam and 2.5 hours in Duisburg. Rederij de Jong estimated that their three largest push vessels consume annually 875 m^3 each. These push vessels can possibly have 2 or 4 lighters.

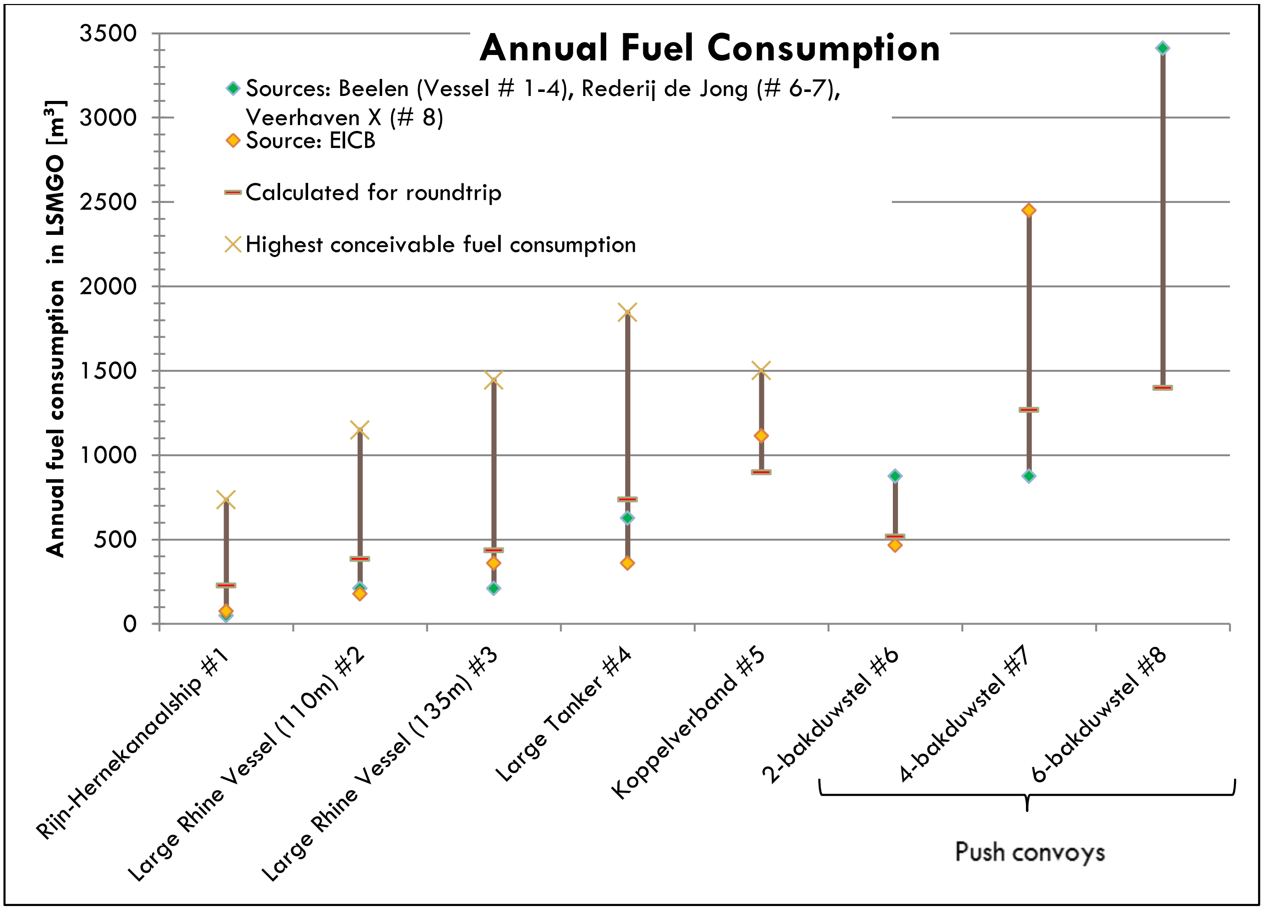


FIGURE 19: FUEL CONSUMPTION VESSELS, OWN COMPOSITION, SOURCES: (BEELEN, 2011) (VIA-DONAU, 2007) (EICB P. I., 2015) (EVO-GASOLIEVERBRUIK, 2011) (GODJEVAC; MEIJ, 2014)

APPENDIX C: REQUIREMENTS, DESIGN AND COSTS OF AN LNG FUEL SYSTEM

Propulsion technologies

This section shows the types of propulsion configurations, which are currently applicable for using LNG as fuel. The different propulsion configurations have great impact on the LNG fuel system, hence the investment to use LNG as fuel.

The number of engines is important aspect to determine the LNG fuel system configuration. Beside the number it is important to know which type of propulsion technology will be used, due to regulations of the propulsion technologies and therefore LNG fuel system. Beside the influence of the propulsion configuration on the LNG fuel system(s), it has also great influence on the type of engine(s), therefor also investment costs. Table 10 shows the different type of propulsion systems possible per vessel and the number of engines. These three aspects have great influence on the total machinery requisite to use LNG as fuel, therefor the initial cost to move to LNG as fuel.

TABLE 10: PROPULSION CONFIGURATION PER TYPE OF VESSEL

		Europe Vessel	Large Rhine Vessel	Koppelverband	Large Tanker / Container	Push Convoys
		CEMT IV	CEMT V	CEMT Vb	CEMT VIb	CEMT VI
Propulsion: no. of screws applicable:	1	●	●	○	-	-
	2	○	○	●	●	○
	3	-	○	○	○	●
	4	-	-	-	○	○
LNG Engine configurations applicable:	Mono – LNG	○	○	○	○	○
	Dual Fuel	●	●	●	●	●
	LNG - Electric	○	○	○	○	○
●	Standard (common configuration)					
○	Optional					
-	Not applicable					

Premixed dual fuel propulsion system

Dual fuel engines are characterized by the possibility to run on two types of fuel, in this case, LNG and LSMGO. Generally these types of engines are derived of normal diesel engines. For IWW vessels, currently, just premixed dual fuel engines are available. This type can run on LSMGO or together with LNG, whereby the share of LNG/LSMGO is an important aspect. DF engines, which have the Otto cycle in gas mode, direct injected (DI) engines are currently available for large seagoing vessels. These DI DF LNG engines, sometimes called gas diesel engine, , which could help to success LNG as fuel for IWW vessels in future.

Mono LNG propulsion system

Lean burn spark ignited mono fuel Otto cycle engines do also have a premixed combustion, rather than direct injection. The engines, and configuration, are technically comparable with the premixed dual fuel engines. Mono fuelled gas engines are applicable for retrofit and new build as well. A major disadvantage of this type of engine is the power available by instant load application.

Gas-electric propulsion system

An electric propulsion system consists out of an electric engine connected to the marine propeller by a shaft. The energy required for this electric engine is produced by a combustion engine and a generator, sometimes called a genset. This can be, in this case, a dual fuel or mono LNG engine. The main advantage of having a combined system, with an electric propulsion system, is the energy efficiency by engines and vessel. Subsequently instant load applications are possible with mono LNG fuelled engines. On the other hand, still two independent electric propulsion systems are required. In case of dual fuel engine, one LNG fuel system is required. In case of mono LNG propulsion, two independent LNG fuel systems are required. This system configuration is expected to be the most expensive and mainly suitable for new build vessels.

Other fuel systems on Board

Auxiliary systems, such as bow-trustors and generators, are sometimes constrained to use gas. These auxiliary systems are outlined in this study, though the extra initial investment costs can be taken into account.

Conclusion, trends and developments

A dual fuel propulsion configuration seems to be the most achievable propulsion configuration for IWW vessels. the advantages outweigh all other propulsion systems. Key advantages are fuel flexibility, fuel security, single LNG fuel system and one engine.

As long as the deadlock of the LNG supply chain isn't resolved, it is expected that a dual fuel propulsion configuration will dominate the market. Fuel security of this configuration ensures that shipping companies can use the cheapest fuel at that moment, or on request of customer LNG as fuel, environmental motivation. This fuel security also ensures that there is no negative return on investment, at times that LNG is in a price disadvantage compared to LSMGO. Besides, this configuration requires the lowest investment to use LNG as fuel, obtaining a loan should be easier with fuel security. Moreover, fuel flexibility ensures to operate at waterways where no LNG is available and the LNG fuel storage tank can be minimized, within spare capacity, to their trading pattern. A smaller sized LNG fuel storage tank will cause lower investments costs, hence lower loan payments, less intake of space and deadweight.

LNG fuel systems by Cryonorm

Figure 20 shows a typical LNG fuel system configuration by Cryonorm. In this configuration a dual fuel (DF) engine is considered, which is most chosen configuration. % of all quotations offered to potential customers were applicable for a dual fuel configuration, even more for IWW vessels, %.

In case of a dual fuel configuration, propulsion redundancy is guaranteed by diesel operation, which is excluded in Figure 20. In mono fuel, DF-electric of mono fuel electric, the LNG fuel systems in Figure 20 are the same, but most systems are redundantly configured.

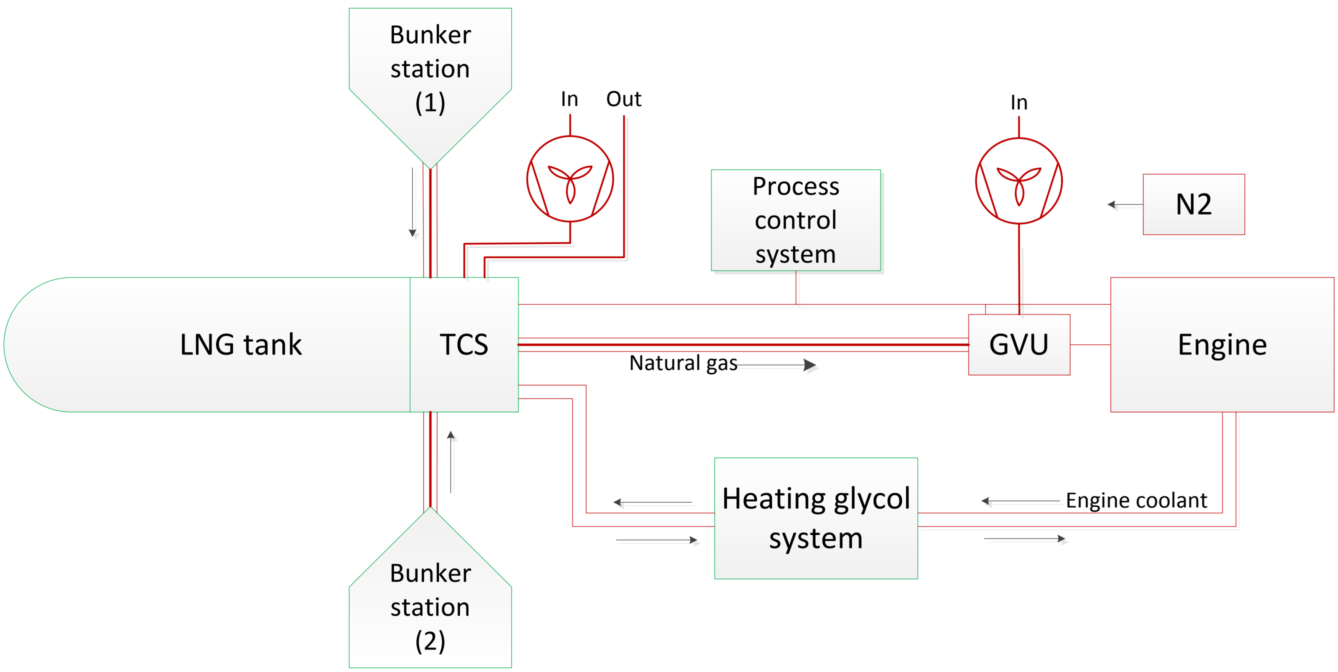


FIGURE 20: LNG FUEL SYSTEM BY CRYONORM

LNG fuel storage tank

LNG fuel storage tanks are made of austenitic stainless steels and are double shelled for vacuum isolation, to respectively withstand cryogenic temperatures and minimise boil off gas. The LNG fuel storage tank mounting constructing is scoped out by Cryonorm, though a fixation is costly, due to weight, load factors and thermal expansion of the fuel storage tank.

LNG fuel storage tanks are mainly the biggest expense of an LNG fuel system. The price of such tank is mainly dependent on its size. For design and operation, filling limits of LNG in the tank must be considered. A minimum filling limit of 5% must be retained to ensure cryogenic cold conditions. Subsequently, there is a maximum filling limit of approximately 83%, dependent on design lay out, density of LNG at blow-off pressure and guarantee of operation of the pressure relieve valves. Therewith, a rule of thumb can be considered that an LNG fuel storage tank has a capacity of approximately 75% of its gross volume.

Tank connection space (TCS)

All cryogenic equipment to process LNG into NG, for fuel usage, is installed inside the TCS. The largest costs unit inside the TCS are the evaporators to maintain operating pressure in LNG tank and to ensure stable natural gas to the gas valve unit (GVU) of the engine. Beside the evaporators, the tank connection space is equipped with many valves to guarantee stable gas supply and safety. Besides, Figure 20 shows the interfaces which are connected to the TCS. Cryonorm design the TCS always directly connected to LNG tank, due to stringent rules and regulations of Cryogenic processes, yet it is possible to separate the tank and TCS. A TCS connected to the short side of the LNG tank is the most common configuration. A TCS connected to the longitudinal side is possible, though it is more expensive.

Bunker systems

A typical vessel is equipped with two independent bunker systems. Cryonorm design and supplies a bunkering module, which is part of a vessels bunkering station. The bunkering model is automatic controlled and ensures safe bunkering of LNG, by truck or pipeline. Besides, a N2 purge connection is presented to take away air out of the system after bunkering LNG.

Heating glycol system and process control system

The heating glycol system, small skid, supplies heat to the TCS. The heat is taken from the engine cooling system, by a heat exchanger inside the heating glycol skid. This intermediate step is required by class societies.

The process control system is a marine approved hardware which interfaces all LNG systems. It automates processes, such as evaporation and handles alarm systems. This system will be visualized by a dashboard for operators.

Gas value unit (GVU), engine and piping

The GVU controls the amount of NG and mixes it with air for engines combustion. This GVU is required for each individual engine. Figure 20 shows the interconnecting piping between each system. The triple lined connectors show the vacuum isolated piping, between TCS and GVU, which is costly, but required by rules and regulations imposed by the CCNR.

Technical requirements of LNG fuel systems

This section shows the requirements imposed by governmental bodies and needs by shipping companies of LNG fuel systems. Design requirements have great impact on LNG fuel systems, hence its investment. Current designed and supplied LNG fuel systems by Cryonorm for IWW vessels are oversized. This section shows the current requirements and future possibilities of LNG fuel systems.

Rules and Regulations

The regulatory framework for IWW vessels is covered by the Europees Verdrag inzake het internationale vervoer van gevaarlijke goederen over de binnenwateren (ADN), the Rhine Vessel Inspection Regulations (RVIR) and the Directive 2006/87/EG, Figure 21 shows this framework.

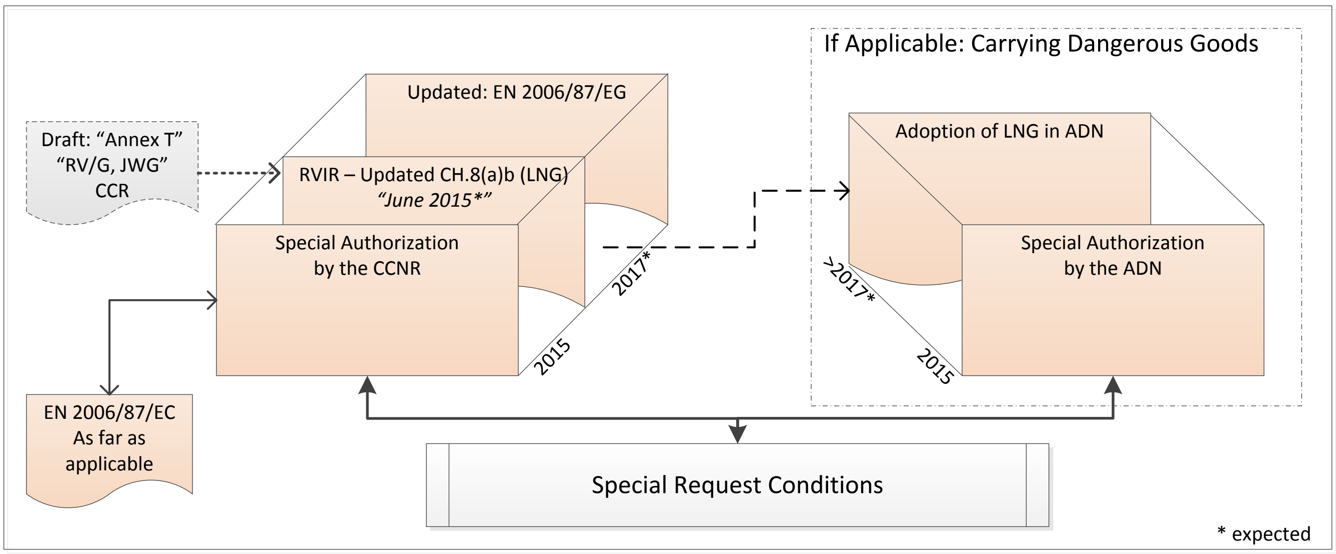


FIGURE 21: REGULATORY FRAMEWORK FOR GAS FUELLED IWW VESSELS IN EUROPE.

There was a prohibition for the use of LNG as fuel for IWW vessels. Though, the RVIR gave ship owners and builders the occasion to develop LNG fuelled inland vessels, by special conditions which were controlled by the CCNR (Central Committee for Navigation on the Rhine), and in case of carrying dangerous goods also by the ADN. (Vermeulen, 2015) In June 2015, the RVIR was updated with the admission to use LNG as fuel, but the special request conditions remain.

The RVIR is updated with the so-called Annex T Draft, which are the rules and regulations for gas fuelled IWW vessels. This Annex T is based on the IGF-draft by the IMO, but impossibilities are changed or ruled out. Such impossibilities are for example a stack of 6 meters in height, which is impossible with bridges on waterways. On the other hand, the special request conditions still requisite that the vessel is built under classification of a Class Society, with rules and regulations for LNG as fuel for IWW vessels, or an expert. This is a legal condition. In practice, the vessels must be built under classification of the Class Societies' Bureau Veritas, Lloyds Register or DNV-GL. (Vermeulen, 2015)

CCNR & Class society

LNG fuelled ships, both seagoing and IWW vessels, build for European market are predominantly build under control of a class, Lloyds Register (LR), Det Norske Veritas (DNV), Germanischer Lloyd (GL), DNV-GL, Bureau Veritas (BV), CCR, KR or Bureau of American Shipping (ABS) which are part of the IACS. Both inland- and seagoing vessels equipped with LNG systems by Cryonorm are built under control of one of these classes. In Figure 22, a relationship diagram is presented how current regulations are made of. All actors are dependent on each other; the arrows and their weight correspond to the extent to which these actors regulate their own "Rules and Regulations". Class societies are in forefront of regulations, because they can adapt regulations quicker and are mainly direct involved technical developments, and overrule most of the time the other regulations. (GL, 2013) The regulations to use LNG as fuel differ sometimes significant among the classes.

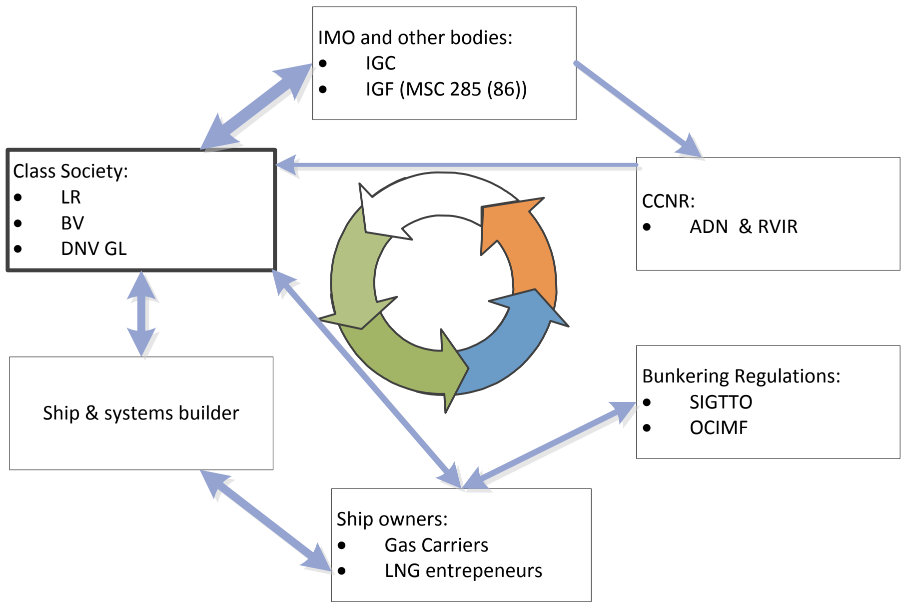


FIGURE 22: RELATIONS BETWEEN BODIES WHO ARE RESPONSIBLE FOR REGULATIONS, CLASS SOCIETIES ARE THE MAIN ACTOR. OWN COMPOSITION, BASED ON (GL, 2013)

Governmental bodies with regulations are reserved to present their final framework of regulations, probably due to the lack of knowledge and ongoing development of LNG fuelled vessels. Therefor their draft or temporary regulatory can easily be enforced by new findings by other actors. Result of this situation is that the requirements for LNG fuelled IWW vessels are enforced regularly by each class society. Besides, the CCNR still request own requirements alongside of the requirements by the class society. It is not expected that this headlock, of requirements of all actors together, will be resolved in the next five years, due to the small number of existing IWW vessels. Currently, this situation results in stringent regulations over time. This results in every time a redesign of the LNG fuel system, with extra costs for materials and engineering as result. (Glorie J. , 2015) Hence, a type approval, in the upcoming five years, of LNG fuel systems can be assumed as unthinkable.

Technical requirements by class societies

The regulatory framework for LNG as fuel for IWW vessels, imposed by the CCNR, is detailed for almost any component or aspect of the LNG fuel systems and engines. Some aspects are for importance of this investigation, namely: the number of LNG fuel systems required and the number and type of engine. On the other hand, special designs can cause an even more expensive investment. It is expected that the aspects of importance are the main cost items of the required investment, see Table 11.

TABLE 11: MINIMUM NUMBER OF LNG FUEL SYSTEMS REQUIRED

	Number of engines			
	1	2	3	4
Mono – LNG	-	2[1]	2[1]	2[1]
Dual Fuel	**1**	1	1	1
Gas - electric	-	2	2	2
DF - electric	-	1	1	1

[1]Inventions can possibly lower this requirement, by the CCNR regulations.

Table11 shows the minimum number of required LNG fuel systems, which consist out of an LNG storage tank and tank connection space (TCS). Cryonorm places the TCS on the LNG storage tank, due to extra safety requirements in these hazardous areas. Loosen up this connection can result in uneven number of tanks and TCSs, but the minimum numbers in Table 11 must be remained.

Requirements for LNG storage tanks by a dual fuel engine configuration

A previous section shows the fuel consumption per vessel for a roundtrip from Rotterdam to Koblenz. Resolving the deadlock of the LNG supply chain, will probably result into a couple satellite bunker stations along the Rhine. Extensive LNG supply chain can reduce the size of LNG fuel storage tanks for IWW vessels. Bunkering large quantities of LNG has advantage on the number of bunker operations and the retail price of LNG as fuel. On the other hand, the advantages of a large LNG fuel storage tank should outweigh the additional loan payments of the more expensive LNG fuel storage tank.

In case of a dual fuel configuration, no safety margin on fuel storage is required, due to fuel security and fuel flexibility. Table 12 shows the minimum LNG fuel storage tank size for a roundtrip Rotterdam – Koblenz. This is calculated by using the filling rate (75%), fuel consumption based on LSMGO and fuels energy densities. (Buthker) No safety margins, engines efficiency or LSMGO replacement rate is taken into account.

TABLE 12: ESTIMATED TECHNICAL MINIMUM REQUIRED TANK SIZE FOR A ROUNDTRIP ROTTERDAM - KOBLENZ

CEMT Class	Type	Fuel consumption roundtrip [m^3 MGO]	Fuel consumption roundtrip [m^3 LNG]	Minimum required tank size (gross)[m^3]
IV	Rijn-Hernekanaalship	5.7	9.3	12.4
Va	Large Rhine Vessel (110m)	8.9	14.6	19.4
Vb	Large Rhine Vessel (135m)	10.8	17.7	23.6
Vb	Large Tanker	19.9	32.6	43.4
VIb	Koppelverband	16.5	27.0	36.0
VIa	2-bakduwstel	8.4	13.7	18.3
VIb	4-bakduwstel	17.7	29.0	38.6
VIc	6-bakduwstel	14.3[1]	23.4[1]	31.2[1]

[1]Roundtrip: Rotterdam – Duisburg.

Large Tanker uses 53.3 m^3 LSMGO on a roundtrip to Basel. This is expected to be one of the most consuming roundtrips in West Europe. Hence a Large Tanker requires a minimum tank size of 116.3 m^3 gross volume. Same, for a roundtrip to Basel with a Large Rhine Vessel (110m) a minimum tank size of 52 m^3 gross volume is required.

The calculated technical required tank size does not imply that this size fulfils the customers' needs. Bunker times, tank costs, operational profile, vessels efficiency are aspects which can influence the final size. This consideration must be investigated case by case.

Costs of LNG fuel systems

In this section the costs of LNG fuel systems for IWW vessels are analyzed, by investigation of their quotations to potential customers. More than quotations (Glorie J. , 2015) for both seagoing and IWW vessels are analyzed, both retrofit as well newly built.

Standard and special design by Cryonorm

The current quotations are offered according to customers demand. Some quotations offered can be considered as a special design other as a normal design.

A design can be considered as normal if the design has the following characteristics:

- Horizontal storage tank placed on deck, within certain distance from the vessels' hull.
- TCS is fitted on a short side of the LNG storage tank.
- Maximum of 2 LNG fuel systems with a tank volume less than 100 m^3.
- LNG bunker stations can be fitted next to LNG storage tank, on deck.
- Vessel engine(s), per tank and TCS, is lower than 2000 kWh.

All other designs can be considered as a special design, which often requires much more engineering, higher material requirements for components, and more equipment. Hence, the costs for such special design are considerably higher.

For example, a design with a vertical LNG fuel tank placed in the vessels' bow:

- Vertical LNG storage tank must withstand longitudinal forces of the vessel while sailing, hence:
    - Special design and reinforced tank.
- TCS connected to the longitudinal side of the tank, hence:
    - Special engineering (labor), due thermal expansion tank and circular mounting space.
    - More labor in workshop, short side is easy to get loose to connect valves and pipes, while longitudinal is far more labor intensive.

Such special design can be considered by customers to minimize the intake of cargo space, mainly at container vessels, and often a standard design can't fit anyway. This special design, within the scope of supply of Cryonorm, can be times as expensive as a comparable standard design.

Cost breakdown of an standard LNG fuel systems

Figure 23 shows a cost breakdown structure of a standard LNG fuel system, applicable for IWW vessels, offered by Cryonorm. For this cost breakdown quotations are analyzed, whereby quotations were complete and comparable to each other. Distinction is made between one or two LNG fuel systems, due the minimal requirements per type of propulsion.

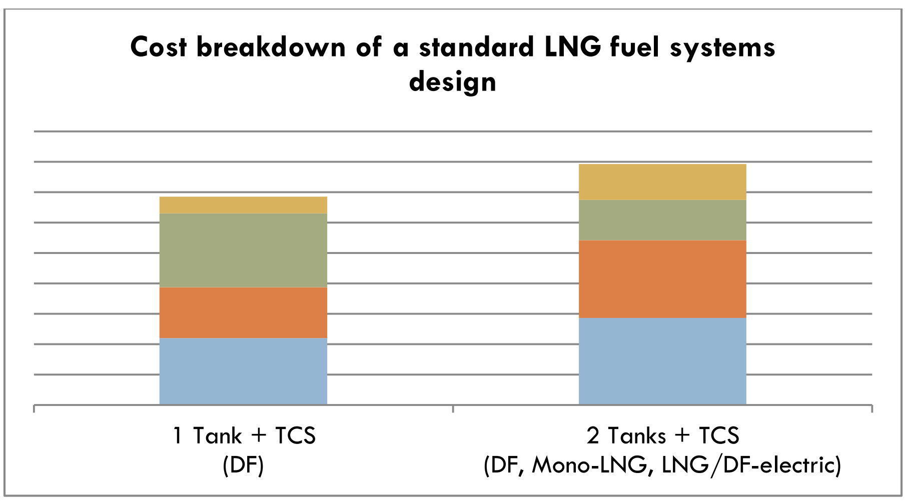


FIGURE 23: COST BREAKDOWN LNG FUEL SYSTEM. OWN COMPOSTION, BASED ON 26 QUOTATIONS

The cost item tanks consist out of the price of the tank, which Cryonorm buys from a supplier. The tank connection space (TCS) consist out of all equipment inside the TCS, the main cost items within the TCS are the evaporators. Labor consists out of engineering and labor within the workshop and on side placement of the LNG fuel system. Cost items others can consist mainly out of transport expenses, certification by class societies. Within the cost breakdown the costs of bunker stations, heating glycol system and process control system are excluded.

Prices of excluded cost items:

- Bunker station: € .- each
- Heating glycol system: € .-
- Process control system: € .-

Price of LNG fuel tanks

As shown in Figure 23 the costs of tanks take in a large share of the total costs of an LNG fuel system. Figure 24 shows the prices of standard LNG fuel tanks opposing their gross volume. The trendline, powers to second, highlights the correlation between size and price of a standard LNG storage tank.

Hypothetically, it could be expected that larger sized tanks would have a favorable cost/volume ratio compared to smaller ones. However the vacuum isolated tank must withstand the vessels forces and the weight of LNG, hence increased diameter of the inner tank has great influence on the structure and therefore price. Eventually the tank volume will be increased by its length and the hypothesis is probably applicable.

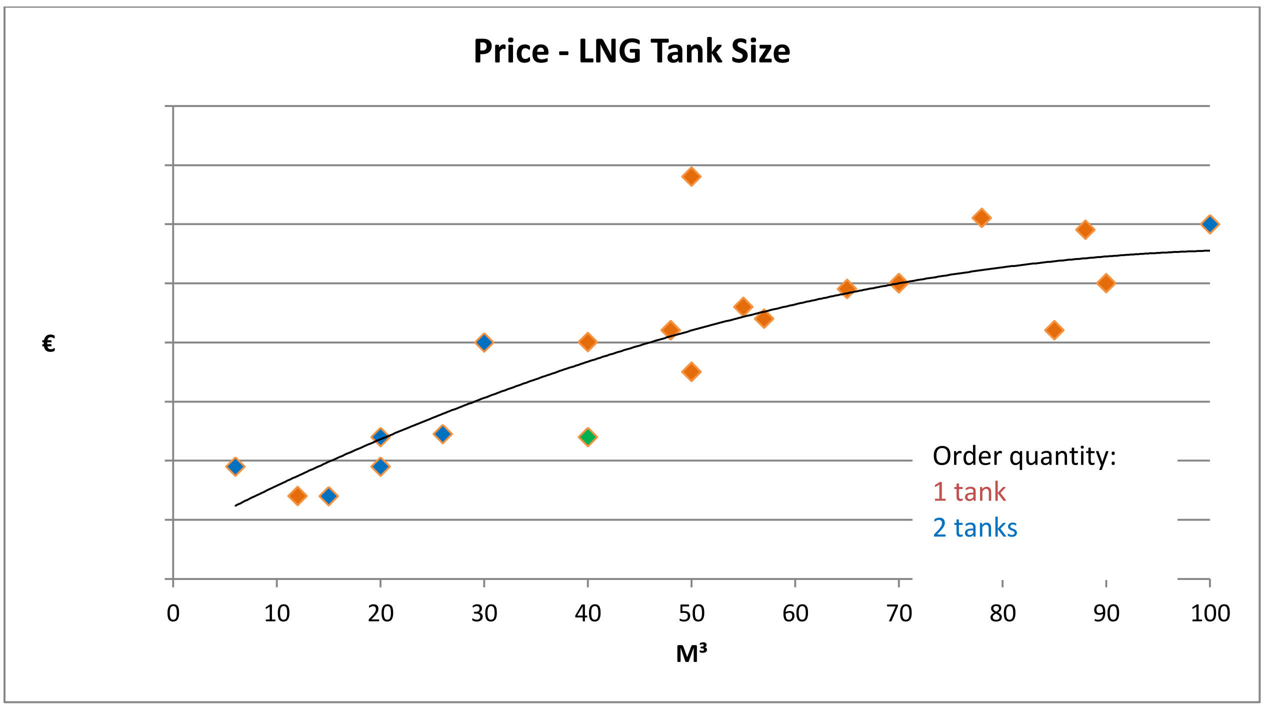


FIGURE 24: PRICES OF AN LNG TANK FOR A STANDARD DESIGN

Figure 24 shows the equation of the trend line, which can be used, for estimation, to eventual weigh out the extra loan payments of a larger sized tanks opposing the bunker costs, which consist out of costs of time, bunker lines and bunker service. If the deadlock of the LNG supply chain is resolved these bunker costs of service can be expected lower.

$$Y = - \quad x^2 + \quad x + \quad , \quad 10 \leq x \leq 100$$

Analysis of costs of LNG fuel systems

Figure 23 shows that in case of double equipped LNG fuel system the labor cost are disproportional low compared to single LNG fuel system. This can probably explained by the few numbers of quotations offered for a double LNG fuel system and simplicity of the design; otherwise it is probably impossible to fit two LNG fuel systems on an IWW vessel. Subsequently the engineering costs were probably ruled out, due to the existence of the Greenrhine and Greenstream, which has such configuration.

The limited higher costs of tanks by a double LNG fuel system can be explained by two aspects. First, the total volume of LNG storage tanks is often comparable. Subsequently, by a double order of LNG fuel tanks, some discount can be expected.

A TCS consist mainly out of two evaporators and values. The evaporators are built by Cryonorm, which are the main cost divers, the values and appendages are supplied.

Best price of an LNG fuel system

In this section, the best price of an LNG fuel system is calculated. In this best case situation a standard design is considered and favorable component prices are taken into account. .
Table 13 shows the best price of an LNG fuel system. As already concluded, price increase can be expected over time by stringent regulations opposed by the CCNR and class societies. .

TABLE 13: MOST FAVORABLE PRICE OF LNG FUEL SYSTEMS BY CRYONORM

Cost driver	Single LNG fuel system [€]	Double LNG fuel system [€]
Others		
Labor		
TCS		
Tank [40 m^3]		
Bunkerstation		
Heating glycol system		
Process control system		
Total:		

APPENDIX D: BUSINESS CASE TOOL OF LNG AS FUEL

LNG Investment tool: LNG for IWW vessels

Advantages and disadvantages discounted ralative to MGO fuelled IWW vessels

Bank Data:

Discount Rate	0.05
Period; NCW=0 [Years]	10

CapEx and Maintenance:

Capex; Initial Investment [€]	
Maintenance (% of CapEx)	0.00%
Maintenance Trend [%-point/year]	0.00%

Indirect Costs:

1	Maintenance	5000
2	Reliability	0
3	Parts	0
4	Oil	0
	Total	5000

OpEx:

MGO/LNG share [% LNG]	100%	
Fuel efficiency LNG [% of conventional]	100%	≠100 fill in LNG price
LNG Price [€/MJ]	0.006	Assumption (Wholesale price: based on TTF gas price)

Gas oil quantity [M³]	4200
Δ€ MGO-LNG [€/M³]	
Trend in Δ MGO-LNG [€/jaar]	0.000
Indirect Costs [€/year]	5000

Required energy [MJ]	1.51E+08
Changed: [Δ€/MJ] (MGO-LNG)	0.001505

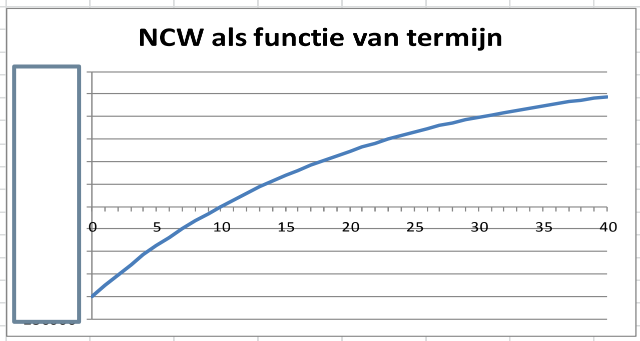
0

Income:

Loss of income [% of reference]	
Cash in extra [% of reference]	

NCW = 0 **IRR =** 5.0%

t [jaar]	$(1+r)^t$	Cash out	Cash in	Cash flow	Discounte	Cumulatief
0	1.000					
1	1.050					
2	1.103					
3	1.158					
4	1.216					
5	1.276					
6	1.340					
7	1.407					
8	1.477					
9	1.551					
10	1.629					
11	1.710					
12	1.796					
13	1.886					
14	1.980					
15	2.079					
16	2.183					
17	2.292					
18	2.407					
19	2.527					
20	2.653					
21	2.786					
22	2.925					
23	3.072					
24	3.225					
25	3.386					
26	3.556					
27	3.733					
28	3.920					
29	4.116					
30	4.322					
31	4.538					
32	4.765					
33	5.003					
34	5.253					
35	5.516					
36	5.792					
37	6.081					
38	6.385					
39	6.705					
40	7.040					



Target NCW 0%

Goal

Report:

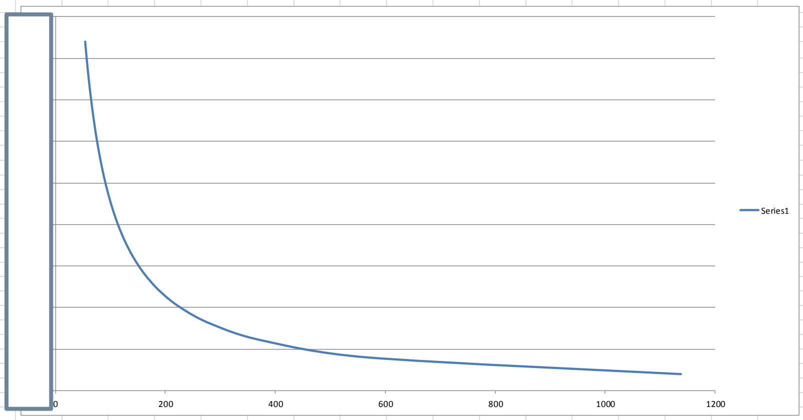
Discount Rate	0.05
Period; NCW=0 [Years]	10
Capex; Initial Investment [€]	
Maintenance (% of CapEx)	
Maintenance Trend [%-point/year]	
OpEx:	
MGO/LNG share [% LNG]	
Fuel efficiency LNG [% of conventional]	
Gas oil quantity [M³]	
Δ€ MGO-LNG [€/M³]	
Trend in Δ MGO-LNG [€/jaar]	

Indirect Costs:		0	0	0
1	Maintenan		0	5000
2	Reliability		0	0
3	Parts		0	0
4	Oil		0	0
0	Total		0	5000

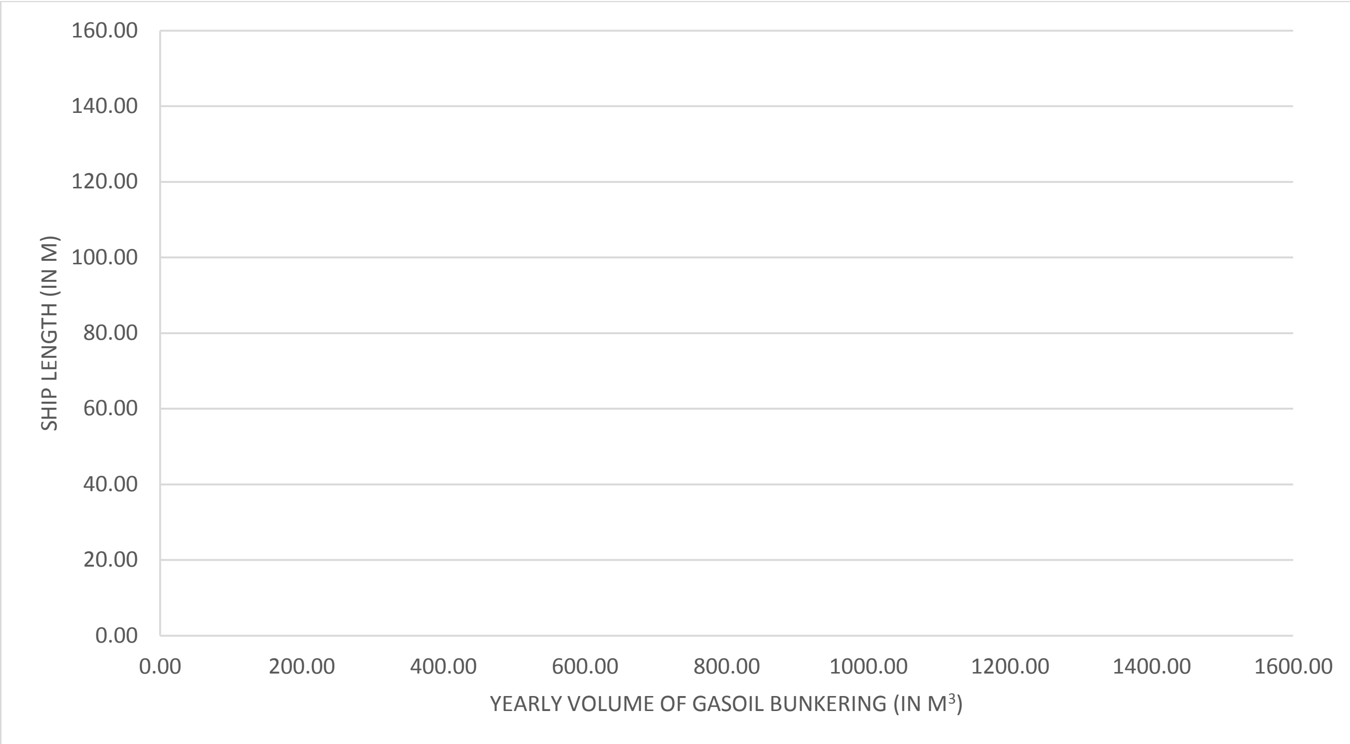
Indirect Costs [€/year]	5000
Income:	
Loss of income [% of reference]	0%
Cash in extra [% of reference]	0%

MGO Quantity [m³]	Δ MGO [r	Δ €/MJ
0		
200		
400		
600		
800		
1000		
1200		
1400		
1600		
1800		
2000		
2200		
2400		
2600		
2800		
3000		
3200		
3400		
3600		
3800		
4000		
4200		

One Way



APPENDIX E: BUNKERING VOLUME OF IWW MOTOR VESSELS



YEARLY VOLUME OF GASOIL BUNKERING (M^3). SOURCE: EICB 2015, DG MOVE