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Is LNG feasible as propulsion energy?

- A case study on container vessels operating in the North European ECA

Mats Gripsrud Laaveg

Supervisor: Associate Professor René Taudal Poulsen

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Preface

This thesis has been written as part of my Master of Science program at Copenhagen Business School (CBS) in the concentration of Applied Economics and Finance, and marks the end of a five year education.

The reason for choosing the topic of LNG as marine fuel can mainly be attributed to the business project I participated in, in the spring of 2012. This project also had an emphasis on LNG in shipping, although it mainly focused on the lack of a global price index for LNG as fuel oil. However, the paper provided me with strong personal interest for the oil, gas, and shipping industry as well as the opportunity to regard LNG from the perspective of the global climate change. And it is in fact in this context, where LNG and shipping may contribute to the preservation of the environment, that I have gotten my inspiration to write this dissertation. In line with the environmental focus, several organizations now pursue a proactive approach to reduce the pollution of ships. IMO, in particular, address their concern and has accordingly directed certain regulations that require conformity by the industry. These regulations have mainly been instructed through the MARPOL Annex protocol where IMO announce the importance of preventing spill and emission of hazardous substances to the marine wild life.

Throughout the work of this thesis, numerous people have provided me with valuable input. In this respect, I would like to thank my supervisor, René Taudal Poulsen, for professional guidance and feedback along the way. Furthermore, I would like to express gratitude to all of my interviewees for their kindness in providing me with important knowledge as well as putting aside time to answer my questions. I would also like to send a special thanks to Leif Abildgaard for the valuable information he has provided me, and finally a gratitude to my loving family. Without their patience and support this thesis would not have come into existence.

Mats Gripsrud Laaveg

Executive summary

The objective of this thesis is to assess the feasibility of using LNG as a marine fuel for container ships that fully operates in the North European emission control area (N-E ECA), and to see under which circumstances it will be the most attractive abatement strategy when complying with future ECA regulations. In particular, this paper seeks to examine the challenges and enablers for LNG, and to study if it is more or less suitable than other abatement technologies on the market.

LNG is one of three main abatement strategies that comply with the regulations of IMO with less ship emission to the surroundings. Among the various regulations established by IMO throughout history, this report will in particular consider air emissions from container vessels and specifically the regulations of MARPOL Annex VI from 2005. It offers the reasons to the environmental friendly requirements imposed by the IMO and presents the characteristics of LNG as a possible ameliorative solution. Natural gas as marine fuel has however a significant obstacle by not being compatible with the existing standard of petroleum related fuel oils. For that reason it can be perceived as a disruptive innovation with the requirement of going through a 'standards war' before it can become the new conventionally used marine fuel in the market. This report will for that reason also discuss the necessary elements that must be in place for the survival of disruptive innovations in the maritime industry.

The analyses of this dissertation have come to the conclusion that LNG as fuel for container ships offers significant environmental improvements as well as cost-competitive properties related to its competitive fuel oils of HFO and MGO. It has however significant barriers in the lack of bunkering infrastructure, high investment cost, and loss in cargo space, but will most likely overcome these difficulties due to a likely increase in LNG infrastructure development, low fuel cost and a higher energy content compared to its competitive fuel oils. Altogether, this report comes to the conclusion that LNG will offer more attractive offerings to consumers than the incumbent standard, and will because of this win the standards war to become the new marine fuel of the future. This study therefore indicates that using LNG as propulsion energy is highly recommendable for container ships.

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Part I: Introduction

1. Research Area

1.1 Introduction

During the last decades there has been an increased focus on the anthropogenic impact on the global environment. Various industries have come under stringent scrutiny to reduce its global emission, and have been forced to modify its current business to meet the new demand. In this regard, the International Maritime Organization (IMO) has issued several environmental regulations to force the maritime industry to act in accordance with the emerging threats to the natural environment. Their most recent edit is the MARPOL Annex VI from 2005 which demands stricter regulation to air pollutants from merchant vessels in selected areas. Particularly, there was set forth more stringent requirements regarding the release of sulphur oxides (SOx) and nitrogen oxides (NOx) from ship exhaust. These regulations require that the sulphur content in fuel oil is reduced to 0.1% by January 2015, and nitrogen content in fuel oil to be reduced by 75% from the current limit, by 2016. The regions declared to follow these strict rules of emissions where named emission control areas (ECA) and were selected based on factors of local climate and soil conditions that made them particularly sensitive to ship emission. The commercial vessels are therefore obliged to comply with this regulation whenever sailing in these areas, which results in the requisite to adjust the day-to-day business.

There is a great reduction potential in emissions from shipping. At current date there are several abatement technologies available that complies with the new rules and regulations of IMO. The ones that are the most commercially attractive are marine gas oil (MGO), HFO with gas scrubbers system, selective catalytic reduction (SCR), and finally liquefied natural gas (LNG). In this thesis, the particular aspect of LNG as fuel will be assessed in the light of its environmental qualities, its economic and technological feasibility, and to its commercial viability.

1.2 The overall objective of the dissertation

The overall objective of this thesis is to assess the feasibility of using LNG as a marine fuel for a container ship that fully operates in an ECA, and to see under which circumstances it will be the most attractive abatement strategy when complying with future ECA regulations. In particular, this paper seeks to examine the challenges and enablers for LNG, and to study if it is more or less suitable than other abatement technologies on the market. It is based on a case study to explore underlying principles affecting the viability of the natural resource.

The dissertation will also focus on the prospective of LNG as a disruptive innovation and study the optimal diffusion of a technological discontinuity in this market. Additionally, it will provide an estimation of the likely success of a novelty as well as disclosing the necessary requirements for a new product‘s embrace in the maritime industry. My academic contribution will thus particularly, be to bring insights from innovation theory into maritime economics and to study the probable viability of green advancements in shipping. It will also provide a framework for analyzing abatement strategies in different types of vessels where it can be used as a template for future studies of new propulsion technologies.

This dissertation will also have a focus on examining the feasibility and advantages of utilizing LNG as marine fuel compared to alternative compliance strategies. Particular attention is given to container vessels operating in the ECA of Northern Europe (The English Channel, North Sea, and The Baltic Sea) and the trade-off between higher investment costs and LNG's advantages in fuel cost savings and environmental qualities. More specifically, it will thoroughly define and elaborate different elements that is needed for natural gas to become the new conventional propulsion energy for the shipping industry, and why it should or should not, triumph its fuel oil alternatives for container ships.

As this dissertation seeks to find the viability of a disruptive innovation in the maritime industry it will be relevant for academics within innovational theory. In this context it will offer key findings of a discontinuous novelty in the trade of shipping, which later can be used as a reference and as comparisons for innovations in other industries. Additionally, it will be applicable to ship owners that contemplate investment decisions to comply with future regulations in an ECA. And, since it will discuss both the advantages and the disadvantages of the resource, it could be of assistance when choosing the optimal investment decision for vessel owners. As a final point, this dissertation will elaborate on the future outlook of LNG as a new marine fuel. In that respect this report can be applicable to port owners and other businesses in the LNG industry.

1.3 Problem statement

Preparing a merchant fleet for stringent rules of emission requires important strategic decisions that usually involve commitment of resources that are difficult to reverse. The monetary dedication that comes in conjunction with an adjustment of a marine fleet is so large that selecting the correct strategy is paramount. Among various abatement strategies available on the current market, LNG is believed by industry journals to stand out as the most economically and most environmental friendly marine fuel (DNV, 2011). However, due to complications of ship design and lack of infrastructure its perceived notion as the new conventional marine fuel may be delayed. In line with market hesitation the research objective will be to investigate the following:

Is LNG feasible as propulsion energy for container vessels operating in the North European ECA?

The thesis will endeavor to provide a conclusion to the attractiveness of LNG by applying two analyses. It will include both a quantitative approach and a qualitative approach, where the former will specifically focus on the following parameters:

a) Investment costs for the various bunker systems
b) The operational costs of the competing strategies
c) Fuel price differences between LNG, MGO and HFO
d) Loss in cargo space of the LNG strategy due to larger bunker tanks

As it is important to look at the product in a holistic way, simply considering the economic effect related to the choice of abatement strategy will not suffice. One imperative factor is therefore to focus on a combined analysis by including a qualitative view on the aspects of macroeconomic theory and innovative theory to explain why or why not LNG is the optimal bunker fuel to use in container ships operating 100 percent in an ECA. The mathematical analysis conducted in this thesis will therefore be supplemented by two theoretical analyses to elaborate further on its findings.

1.4 Scope and delimitations

As a result of the selection of providing a narrower study of LNG as marine fuel, an important delimitation of this analysis will be short-sea shipping. An illustration in this regard is the chosen area of study to be the North European ECA, and the typical vessels operating in these waters. Although LNG also can be applied to larger vessels operating over long distances, the lack of the present and near future infrastructure will limit the attractiveness of LNG to those sailing over shorter distances, with fixed sailing routes, and those that have proximity to bunker fuel stations.

The choice to focus on one shipping segment exclusively is another delimitation that needs to be accounted for. As one of the objectives of this study was to examine LNG more extensively, I chose to examine container ships and the typical feeder vessel observed in the N-E area. To limit the complexity I chose to study one container vessel operating in the ECA and found the most representative liner vessel to be a ship with the size of 1000-1500 TEU after discussing it with my interviewee from Wärtsilä. Average engine load, fuel usage per g/kwh, engine power, and forecasted operating hours per year are all used to estimate a typical operating ship sailing in the region, even though this will not represent a general vessel. These preferences obviously create difficulties in generalizing the discoveries to other ship types and sizes. Nevertheless, the study still manages to provide a model and framework to describe how similar vessels can be analyzed in the future.

Although this thesis largely regard container vessels in isolation, the decision of investments in abatement strategies will have to be considered in conjunction with other maritime segments than this sector only. It is important to take into account that this segment only acts as one small part of the aggregated maritime industry, and that any potential environmental adjustments to greener ocean traffic depend on the maritime industry in total. Additionally, the sustainability of any disruptive innovation, like LNG, is in need of large network effects (Katz and Shapiro, 1994) that only can become possible with large scale LNG infrastructure and large customer demand. Accordingly, one ship division alone is not large enough to work as a front runner for a greener shipping technology.

This case study relies on the technical status of the various abatement strategies today, even though technical advances are likely to happen in the future. Furthermore, energy prices are also analyzed from today's standpoint with ambiguity of its development in the future. In conclusion it can be difficult to forecast the exact future competitiveness of the different techniques due to these limitations.

Due to the cost, complexity, and time of the adjustment, where the vessels are out of service for an extended period, it is seldom profitable to modify existing ships to run on LNG (Wärtsilä, UF, 2013). As this operation is costly, retrofitting ships to run on LNG have mainly been done as tests to view the feasibility of the technology, and have merely been conducted in collaboration with governments or large organizations that financially support the procedure (Wärtsilä, 2013). As a result of this economic disadvantage, LNG-driven vessels are largely limited to new ships only which induce this report to neglect the alternative of retrofitting existing ships.

1.5 Thesis structure

In order to ease the reading process, I will structure the dissertation in four main parts: Introduction, Background, Case Study, and Conclusion. For further simplicity, this thesis will be divided in ten chapters: The research area, literature review, theoretical framework, methodology, background, ship owners' compliance strategy, LNG supply chain, quantitative analysis, qualitative analysis and conclusion.

The first part will undergo the part that *introduces* the study. It will encompass 4 sections, where the first one will describe the *research problem* and place the study in context with the current situation. This is where the thesis question will be raised and discussed to serve as a foundation for the rest of the study. This first part will also contain the chapter of *literature review* which will discuss the current literature on the subject and refer to key studies and empirical researches that are closely related to the chosen topic. Altogether, this second section will provide a thorough overview of the relevant literature, and will uncover aspects of the subject that allows the reader to understand the particular issue the study addresses. The third section will present the *theoretical framework*, and will be applied to define the academic discourse of the dissertation. In particular, it will include an outline of existing theories and tools that are closely related to the research topic, and which will provide as a base from where evidence on the LNG feasibility can be drawn objectively. The next and last section of part 1 is the *methodology*. Its purpose is to provide an overview of the tools and strategies used to gather data, and to create a base for the upcoming analyses. Primarily, it will offer a theoretical foundation to understand the systematic methods that has been applied in each specific section.

The second part of this study will encompass the *background* of the industry. It will endeavor to undergo a description of the current action of the shipping industry and depict its effect on the surrounding environment. The section relating to *ship owners' compliance strategies* demonstrates the alternative technologies that are available in order to comply with the regulations of the Annex VI fronted and enforced by IMO. LNG supply chain will describe the various bunkering solutions currently possible, critical port criteria in relation to LNG, and the actual LNG supply chain of extracting the resource to providing it to end customers.

The third part will work as the main part of this dissertation and include the case study of the paper. It will include both the quantitative and the qualitative analysis, and provide an intersection between these two theories to find a suitable response to the research question. It will attempt to discuss this issue in an objective fashion and provide a foundation to the conclusion in this report.

The fourth and final part is the chapter encompassing the *recommendation and conclusion*. This part will provide an answer to the problem statement and present recommendations to the shipping industry in how to facilitate a transition concerning the LNG adoption for container vessels, should it be the optimal abatement strategy.

2. Literature review

To conduct a thorough research analysis of the feasibility of LNG as marine fuel, a comprehensive understanding of the existing academic work is required (Blumberg et al. 2005). The following part will thus refer to the existing literature addressing the chosen subject and help providing an overview of the current situation. The existing literature that will be described below relates mainly to two different segments: the industry literature written by large industry organizations, and maritime industry journals where articles are written addressing the players that operates in the industry. Additionally there exist some articles related to LNG written by scientific researchers. However, as this selection of academic literature is sparse it welcomes new reports on the subject.

2.1 Industry literature

Presently, this existing body of industry literature is guided by organizations such as the Danish Maritime Authority (DMA), Det Norske Veritas (DNV), Lloyds Register, and Germanischer Lloyd which emphasizes on the importance of reducing ship emissions to the surroundings. In this context they direct their concerns for the maritime environmental future and contribute with elaborations on various abatement strategies to comply with the new regulation commencing in 2015 and 2016. LNG, in particular, is an alternative thoroughly discussed and is presented as having both environmental and economic advantages when used as ship fuel. Several projects, with the examples of DMA (2012) and Germanischer Lloyd (2012) devote their papers entirely to LNG as marine fuel to contribute to further knowledge around its technological feasibility. The main conclusion of these reports and projects mentioned has been that LNG is both a viable and feasible resource as a marine fuel for the shipping industry. This conclusion has been drawn after thorough comparisons to other emission reduction strategies subsequent to cost-benefits analyses and considerations of potential enablers as opposed to potential barriers. As it is highlighted in DMA (2012), LNG is still in its infancy and has in spite of its beneficial characteristics significant impediments before it can be embraced as the new conventional propulsion energy. The most significant barriers that these papers address are related to the lack of infrastructure and the significance in investment costs which will be elaborated later in this paper.

Some reports, however, go beyond the basic analysis of abatement strategies in conjunction with the environmental impact, and demonstrate their thorough research by applying different elements describing the present situation of the area. MIT (2010) is an illustration in this regard as it implements a discussion around the geological aspect of retrieving natural gas resources in the world. Lloyd's Register (LR) (2012) and DME (2012) are other examples who include parts depicting the recycling industry for ship owners and sections concerning hull design as an energy saving technique.

Other organizations have a somewhat different focus than the current business behavior of ship owners. EIA (2013), for instance, focuses on the world energy outlook, while HELCOM (2010) considers specifically the environmental ecosystem of the Baltic Sea, and examines closely the factors that affect the maritime bio-network. In this relation, it describes the Baltic Sea to be highly susceptible to environmental impacts of human activities, and blames the current negative condition on the release of general garbage and harming substances from the transport sector, among others. They state the environmental situation of the area to be impaired and severely damaged, with none of the open basins to have acceptable status. HELCOM advocates the striking conclusion that the capacity of the marine ecosystem to deliver goods and services has become widely overestimated and that both natural characteristics and human activities challenge its recovery. DNV (2011), DMA (2012), IMO (2011), and LR (2012) are some among many reports that argue that the shipping industry in particular is a big contributor to the grave development of the local environment, and that the main reason is the release of nitrogen oxide (NOx), sulphur oxide (SOx), Carbon dioxide (CO_2), and particular matter (PM), specifically. One demonstration of the human activity in the area is the claim of DNV (2011) that the region is one of the busiest trading routes in the world and that its trading volume, of 822 million tonnes (2008), comprise of around 11% of the total shipping volume worldwide. In other words, the existing literature advocates the shipping industry to play a main role in the harmful development of the region.

2.2 Maritime industry journals

Riviera Maritime Media's industry journal, 'LNG World Shipping', state in an article that regional authorities, national administrations, trade associations, and port authorities in the regions of Europe, North America, and Asia are all warming to the idea of using LNG as marine fuel. According to the journal, they view the resource as being an attractive alternative to the stringent ship emission regime commencing in 2015, and agree on the importance of a joint approach across industry and regions. As many other key players of the industry, they believe that the lack of LNG infrastructure is the biggest challenge for adoption.

Marine Engineers Review (MER) discusses the utilization of LNG in their monthly releases and depicts the development in gas-to-liquids as marine fuel. MER has a positive view of LNG as propulsion energy but look at its advancement with critical eyes. The emphasis is mainly on the lack of infrastructure and manning issues with the associated need for training programs. It has a rather holistic and objective viewpoint addressing both the benefits and challenges with the emerging bunker fuel while simultaneously discussing the challenges of economics and fuel alternatives. In this context, they discuss the plausible future demand for the natural resource.

The Maritime Journal also poses the question of the feasibility of a greener technology by publishing the article “Low sulfur timetable impossible?” (Maritime Journal). They front the industry players that consider the 2015 deadline for SOx reductions to be impossible. As activists for greener technology suggest the use of MGO/MDO, LNG, or scrubbers for vessels that continue to run on HFO, market players respond by calling these proposals unrealistic. They argue that LNG is an option for new vessels only due to the prohibitive cost of converting existing vessels and that the existing and planned infrastructure is inadequate. They continue by claiming that the financial support from authorities is absent leaving sudden modifications to existing ships unachievable. “Our only option is to use marine gas oil (which is) technically straightforward but very costly…” The article continues by quoting ferry operators warning authorities that they will not manage to pass on the extra fuel cost of around 70% to end users, which inevitably will “push up to 50% of cargo off short-sea ships and back on to the road network”.

2.3 Academic literature

Per Kågeson (2005) published a paper for the Centre for Transport Studies Stockholm regarding shipping industry’s future use of marine fuel. In his study he compares the effectiveness of different shipping fuels in terms of cost and environmental impact. His main focus is however on the pros and cons of LNG where he advocates that natural gas is a strong candidate due to its cleanness and the global abundance of the resource. He continues by asserting its likely growth in popularity as the gas price is expected to stay low due to the abundance of the resource worldwide. Additionally, because of enhancements in technology there is also an expected increased rate in exploration and extraction of shale gas which would increase this plethora further. Should a possible future tax or payment from CO_2 emission be implemented, the influx of gas related marine fuel will likely be even more dominant.

Besides Per Kågeson I have difficulties finding other academic articles that discuss the use of LNG as marine fuel. All that exists are discussions regarding different resources, and their possibility to be used as fuel oil. Semelsberger et al. (2005), for instance, discuss the possible utilization of Dimethyl ether (DME) and hydrogen; Bengtsson et al. (2011) advocate the use of second generation bio-fuel; while De-gang Li et al. (2005) promote the use of ethanol. Although these types of strategies undeniably are interesting, they face technological challenges and are thus not perceived to be developed enough to provide an efficient solution to the current industry problems (Semelsberger et al. 2005). The resources mentioned above are simply in their infancy and require accordingly further research in order to become viable alternatives to the most recognized strategies of MGO, gas scrubber, and LNG. As a result, these strategies will not be elaborated further in this thesis.

Although there exist a large literature base concerning the subject of LNG as marine fuel I found it difficult to locate studies that focused on one type of commercial vessel in particular. It proved to be demanding to come across any report that was directed to one specific audience, except to vessel owners in general and those in particular interest. Most of the large reports published by the prominent organizations mentioned have a rather general view of any vessel type and focus more on the fuel type's implication to the surrounding environment, and how abatement strategies can alleviate this negative development. What is interesting is that they all appraise the environmental and economic advantages of LNG as marine fuel, but leave the subject of study without performing a narrower investigation on the challenges of LNG to become the new *standard* as marine fuel. As it is incompatible with neither the existing infrastructure nor the current practices, LNG can be categorized as a discontinued innovation with the threat of disrupting the existing maritime industry. In its path to become the new conventionally used marine fuel, LNG faces large obstacles in its need of overturning the petroleum-based transport industry. The question of focus will thus be how gas successfully can combat petroleum related fuel oils to win the standards war and to convince the maritime industry that gas is the new future. Consequently, this dissertation will focus on the theoretical grounds for the success of disruptive innovations and how such novelties can become the new industry standard. Additionally, it will emphasize on the segment of container vessels located in the N-E ECA, and what abatement strategies a typical feeder vessel ought to implement for both economic and environmental improvement. The benefits accrued to this paper will thus be recommendations and explanations of which specific emission reduction strategies that are best suited for container feeders, in addition to detailed explanations regarding disruptive innovations in the maritime industry.

3. Theoretical and methodical framework

The theories and analyses embedded in this dissertation are utilized to support the research question and any conclusion drawn from it. As this paper has the objective to find the optimal abatement strategy for container vessels, I will consider literature on both innovation theory and investment theory to be relevant. In this context, I chose to focus on elements that are essential to perform such analyses, and will additionally elaborate on macro economical factors that may affect such a financial stand. These theories have been chosen to better reflect the ship owners' point of view, with the ultimate purpose to answer why they should embrace LNG as abatement strategy, or if other solutions will be better suited.

3.1 PESTEL analysis

Although forces within an industry are important to assess and evaluate any possible investment position, the initial importance for executives is insight and awareness of the surrounding business environment (Thompson, 2001). Whenever the environment is dynamic, complex, and unstable, an organization requires a top management that is vigilant and attentive to conduct intellectual decisions (Johnson et al. 2011). In turn, this will depend on information gathered by the organization where sources of external information become increasingly important. Decision makers are therefore reliant on their comprehension of the extensive external environment, and furthermore to which industry its company is interlinked. Consequently, the relationships between a firm, its suppliers, the supply chain, and subsequently the economy as a whole, become an important element of study.

Through his article published by Harvard Business Review (1987), Henry Mintzberg used the term 'crafting strategy' to explain how executives learn by experience and concurrently adapt strategies to fit the surrounding environment. He saw the process as ‘molding a pot of clay’, and used this analogy to illustrate how a corporation requires modifications to suit the business situation as best as possible. The PESTEL analysis is a similar method and builds upon the same framework. It is an abbreviation of its consisting elements where political, economical, social, technological, environmental, and legal matters play important roles in determining factors that influence the industry (Thompson, 2001). All the individual factors hold importance in molding the organization towards an optimal business position. The *economic* condition of the environment is a variable that affects the profitability of a firm. Johnson et al. (2011) refer it to macro-economic factors such as interest rate, exchange rate, business cycles, and differential economic growth rates around the world which all have great impact on corporations. The demand in particular is shaped through these quantitative measures, and will subsequently affect industries and its related companies significantly.

Economical change can as well be a product of *political* conditions, as governments have major implications on the economic state of a country. Currency, as well as political instability, trade barriers, and intervention in legislations do all interfere with an organization's behavioral attitude. Demonstrations in this context are trade unions like the European Union, higher charges in taxes and fees, and governmental decisions regarding health and natural environment. The *socio-cultural* environment comprise of various custom practices and beliefs which often characterize the population of a nation. According to Thompson (2001), the socio-cultural variable is a factor that encapsulates demand and taste which vary with life-style, fashion and disposable income. *Technological* influences refer to innovations that give rise to disruptive technologies, where an established trajectory of performance is redefined and transformed due to these advances (Christensen and Bower, 1996). *Environmental* pressure relates to weather conditions, climate, and climate change which growingly have become an important part of governments' yearly agenda. Finally one has the *legal* variable which embraces various legislative constraints that might change the activities of corporations (Johnson et al. 2011).

All these factors are important to take into account when making any investment decision. Variables such as the ones described, form the organizational behavioral attitude towards any verdict and evaluation of an investment proposition. A PESTEL analysis is therefore perceived to be central to implement in answering the research question, and vital when recommending one selected technology in the concluding report.

3.2 Innovation theory

There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things.

- Niccolò Machiavelli, *The Prince*

Markets are usually dynamic, and with the need of adoption, market players seldom stand still. Companies tend to leapfrog one another to precede any competition in terms of product improvements, cost reductions, and enhancements demanded by customers (Morris et al., 2008). In this regard, all organizations need to adjust to different situations in order to sustain current activities and to develop growth. While some changes are made voluntarily to pursue a certain strategic direction and to increase revenues, market share, and efficiency, others are made as a response to a strategic threat, market share decline, and risk for stagnation (O'Sullivan and Dooley, 2009). This incurs that the principal mechanism for change in any organization is innovation.

According to Sullivan and Dooley (2009), innovation is the process of making changes to something established by introducing something new that adds value to customers. It is utilized to get ahead of market competition, to discredit any comparisons of a similar product, or to create new markets with new demand and no competitors. The primary objective is to forge links to match the patterns of requirements and demand for each technology or industry. It is therefore a process of coupling demand to product, or vice versa.

A fundamental part of innovation theory is to understand the underlying explanation to why some innovations persist, and why others fade away. In this connection, the main focus will be related to the uncertainty of an innovation, the possibility to forecast an accurate diffusion curve, and lastly the potential viability of a disruptive innovation. This part regarding the discussion of innovation theory will thus provide a qualitative stand point of the possible prevalence of a novelty like LNG. Additionally it will present a base from where conclusions of innovational grounds to implement engines running on natural gas can be drawn objectively.

Diffusion of innovations

History has depicted a trend where newer technologies continually are replacing established equipment. When related to marine energy, one illustration could be how steam replaced sail, which in turn was replaced by combustion engine. Although having this in mind, newer technologies are not necessarily adopted by all market players immediately, or even at all. A diffusion process is set in motion.

According to Everett Rodgers (1995), diffusion is the process through which an innovation is communicated through certain channels over time among members of a social system. He states accordingly that these characteristics are founded on 5 main elements, where these variables are divided under the section of "perceived attributes of innovations". He states that these factors consist of (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability. The *relative advantage* is described as the degree to which an innovation is perceived as better than the idea it supersedes. Subsequently, Rogers describes *compatibility* as the way an innovation is perceived as being consistent with existing values, past experiences, and needs of potential adopters. *Complexity* is depicted as the degree to which an innovation is perceived as difficult to understand and used. *Trialability* is portrayed as to which degree an innovation can be experimented with on a limited basis, and finally *observability* is illustrated as the degree to which the results of an innovation are visible to others. Rogers concluded by stating that an innovation that is perceived by individuals as having compatibility, trialability, observability, *greater* relative advantage, and *less* complexity will be adopted more rapidly than other innovations.

These five characteristics can also be viewed in the light of how early an individual or organization adopts the novelty. One illustration in this respect is how a product travels through a birth-death cycle referred to as a Product Life Cycle (PLC). The progress is portrayed by Magnan et al. (1999) as the 'product's life' from introduction to decline and can be seen in the figure 2 below.

This diffusion of innovations is a depiction of the growth in demand, acceptance, substitution, and finally the utilization of a product where its main ability is to forecast a market potential (Norton and Bass, 1987). Rogers (1995) stated that the rate of adoption will increase with the perceived relative advantage of the innovation. This in turn, entails a faster adoption of LNG should its perceived ability be high and its barriers for utilization be low. In the following section I will therefore depict the product's life cycle, and explain how a product is diffused during its life time. Rogers (1995) classify five adopter categories on the basis of their degree to rapidly adopt an innovation. He categorized them as (1) innovators, (2) early adopters, (3) early majority, (4) late majority, and (5) laggards. Magnan et al. (1999) arrange the product's life cycle in four parts referring to the introduction of the product, its growth, its maturity and peak, and subsequently its decline when the product is perceived as obsolete and no longer optimal for usage. It is a diagram of how a product, service, or a business evolves over time, and can be used to map product opportunities through an expected life cycle. PLC management is thus important as it can be used as a strategic anchor in the strategy process where the best practice can improve the quality of decisions, and minimize potential problems during the development. As illustrated in the figures below, any innovative product in its non-cumulative forms takes on the shape of a bell curve with perfect symmetry. Through this representation it is clear that one may estimate the life time of a product, in addition to what time the peak of the diffusion occurs.

Figure 1: Diffusion of innovation

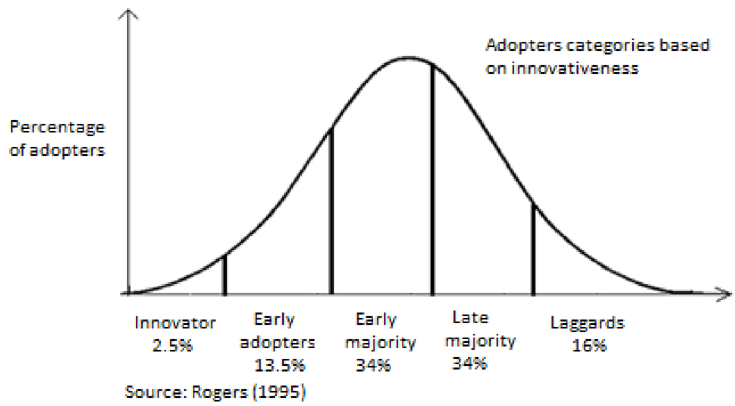
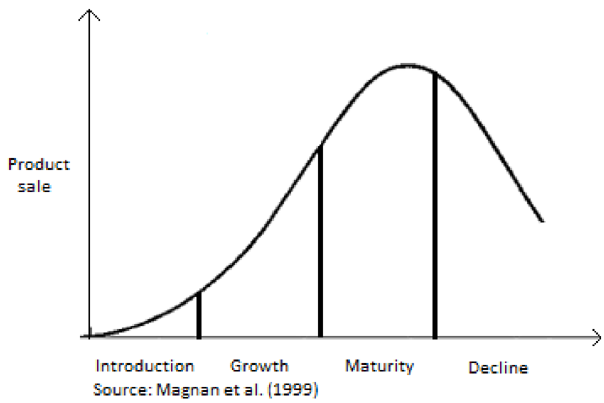


Figure 2: Product's life-cycle



Disruptive technologies

The replacement of obsolete technologies can also be viewed through theories referring to "disruptive technologies" - innovations that revolutionize an industry with new technological capabilities. Christensen and Bower (1996) define an innovation as disruptive if it goes on to disrupt an existing market by displacing an earlier technology, and eventually creating a whole new value network. Josef Schumpeter (1942) calls this process the creative destruction of an economic structure, where the established industry will be overturned due to the introduction of a new product that is not compatible with the incumbent technology. It is the evolution of industries with a series of successive technology cycles originated by technological breakthroughs with dominant design (Richard Foster, 1986). Foster states that once a design becomes a standard it establishes a trajectory for future technical progress that changes the basis of competition in the industry.

An important issue in relevance to disruptive innovations is compatibility and the possibility of one component that work in one system to also work in another system. In this context it is possible to evaluate the maritime industry. In this market, the current infrastructure is compatible with petroleum related fuel oils only, meaning that all the constituents of the industry are related to the technology associated with petroleum. As LNG and petroleum only work in their respective system, these technologies will be incompatible propulsion methods. And because of this, LNG will have to go through a battle of standard design, the so-called 'standards war', before it can be successful and become the new conventionally used marine fuel. In this sense, it will be a combat for market dominance between two standard designs that concurrently are incompatible technologies.

In relation to standard design one important constituent is the element of network effects. Its influence is demonstrated by the increased value of a system the more users joining and enlarging the network (Katz and Shapiro, 1994). This means in effect that offering users access to a larger network is like offering them a better product. In essence, offering large network effects combined with improved attributes compared to the current system will help a network owner to guide consumers towards a new technological standard. However, the problem occurs when the adoption of one system merely leads to being "locked-in" to the associated design and network. This forces consumers to anticipate the likely events of the second period where they ought to be convinced that their selected direction is superior to the alternative. Correspondingly, the key issue will be what the owners behind a system network can do to influence consumer expectations. Katz and Shapiro (1994) suggest that making binding commitments, like a promise to keep future prices low or to engage in expanding the system geographically, will suffice to get the ball rolling. Even backing the product with a strong brand name could be sufficient. The fundamental part is however that network owners have to offer more attractive terms and better offerings than the competitive technology.

Jin Chyung (1996) advocates the necessity of 6 variables whenever establishing a standard for technologies. These six are: (1) Building a large installed base, (2) building complementary goods, (3) have market acceptance, (4) building alliances, (5) margin: cost vs. price, and (6) open versus closed platform. Considering a standard design, building a *large customer base* is vital. It includes having network effects where the value of the service is larger the more consumers that utilizes the network. The compatibility variable somewhat refers to this fact as well, as it asserts the importance of building *complementary goods* to work on that standard. One illustration of this can be how diesel engines are compatible with numerous of equipment, both on land and at sea. The part discussing *market acceptance* describes the importance of delivering a service that is demanded by the market. *Building alliances* points to the fact that this 'market acceptance' may take time and that one might need the support from suppliers producing complements to make a transition more rapidly. *The margin* refer to the issue of not anticipating making immediate profits, while the factor relating to the type of *platform* suggests the importance of having an open standard with availability and compatibility to function with other technologies and equipment.

In conclusion, the theoretical analysis will encompass both the method of PESTEL analysis and innovation theory to provide a plausible explanation should there be any discrepancy between the quantitative analysis and the qualitative analysis. The innovation theory will describe what elements that is needed for an innovation like LNG to persist, and why one innovation will succeed over another. The PESTEL analysis will, on its side, include a discussion of which external factors that are essential for a product to prosper. Together, these theories merge into the possible explanation of why a product opportunity is viable, which is one of the main parts this thesis strives to disclose.

3.3 Investment theory

Seitz and Ellison (2005) define investment by the desire to financially assist a second party or instrument in order to reap a potential gain in the future. Reilly and Norton (1995) illustrates this as well as they describe an investment as the current commitment of dollars for a period of time in order to derive future payments that will compensate the investor for (1) the time the funds are committed, (2) the expected rate of inflation, and (3) the uncertainty of the future payments. They continue by explaining it as a deferral of consumption followed by an uncertainty which in turn requires a sufficient compensation, namely a rate of return. However, as the literature depicts different classifications of assets I will in context with this dissertation neglect the financial aspect of assets and rather emphasize on nontraditional assets, the real assets.

Bodie et al. (2010) explains the investment theory further by implementing a more detailed description of real assets and its role in the economy. They state that the financial system is determined by the productive capacity of its economy, and that producing goods and services ultimately decides the material wealth of a society. In order to emphasize this distinction, they separate the two forms of financial classifications and depict the real assets to generate income while the financial assets simply define the allocation of wealth among its owners. In light of a ship owner, an investment in real assets will describe the purchase of a physical and tangible asset in a shape of a boat that will generate income based on its material body and function. An investment in financial assets however, describes an intangible asset as the contractual right of ownership. It is within this description I will conduct my economic research, with the objective of finding evidence of why investments in environmental friendly real assets will reap future benefits, and if LNG in particular will be the superior alternative. The means utilized to find a likely economic description of the potential viability of LNG is the net present value (NPV) method and the payback time rule.

3.3.1 Net present value

In the present section I will elaborate on the two economic analyses that will provide a quantitative view on the attractiveness of investments within emission reduction strategies. Specifically, I will conduct analyses based on the tool of the NPV instrument and the payback method. These two methods have been chosen to reflect the economic appearance of the individual abatement strategies, to mirror the expected return on investment, and to see the potential profitability of a project. Together these analyses will create my economic stand point and provide one perspective to why ship owners should implement one specific emission reduction strategy.

One of the main questions the investment literature strives to explain is whether the future benefits of an investment are worth the financial outlay required. One of the measures commonly used in this regard is the method of net present value (NPV). The measure is a calculation based on the future expected cash flow given an estimate of the opportunity cost of capital[1], and has the advantage of providing a direct measure of the dollar contribution to its owners (Sharpe et al. 1998). DeFusco et al. (2001) define the NPV as the present value of cash inflows minus the present value of cash outflows, and suggest performing an investment whenever this measure is positive. When it is, the theory depicts an expected cash flow that will exceed the opportunity cost of the capital that is needed to undertake the investment. Consequently it will increase the economic profit for the financier.

[1] Opportunity cost of capital is the alternative return that investors forgo in undertaking the investment (DeFusco et al.2001)

Whenever performing economic analyses based on the NPV rule it is important to consider the following formula:

$$NPV = \sum_{t=0}^{N} \frac{\mathrm{CF_t}}{(1+\mathrm{r})^{\mathrm{t}}}$$

Where:

CF_t = the expected net cash flow at time t

N = the investment's estimated life

r = the discount rate or opportunity cost of capital

t = time

3.3.2 Disadvantages of NPV

Although NPV has proven its value in economic investment decisions, it has several disadvantages that require consideration. Magni (2002) illustrate its weaknesses by emphasizing on several aspects of its form and rigidity. Primarily, he points out how its low level of flexibility limits its possibilities significantly. In this regard he points out the requirement to apply only one level of risk throughout the project's time horizon, and discusses NPV's sensitivity to discount rates where only a small alteration can change the conclusion of an investment decision. Furthermore, he describes the obligation to have equality in risk whenever comparing two alternative investment opportunities. As he said, *"the classical theory does not tolerate the incomparability of oranges and apples"*, which accordingly illustrates how any inconsistency of risk also will be unfortunate for any NPV conclusion. This inference concludes that the NPV obviously is unable to manage a comparison of widely different investment strategies, which entails the researcher to be utterly cautious should any dissimilar strategies be compared. For this reason, NPV analyses are optimally conducted to decide whether a single project is worth investing in. Finally, Magni (2005) demonstrates how the NPV model is deficient in its possibility to incorporate real options of an investment. This lack of including the value of an option to expand, defer, or abandon a project will also provide evidence of its limitations.

As a conclusion, the existing literature perceives this investment measure as a useful starting point to the evaluation of any financial outlays, although additional factors ought to be included should a financial recommendation be reliable.

3.3.3 Payback time

The payback rule is defined as the amount of years it takes to generate the cumulative revenues needed to pay back the initial cost of an investment (Brealy et al. 2011). It is one of the simplest and most comprehensible measures to communicate the likely profitability of a project, and is used as a determinant of whether to undertake a financial position or not. Longer payback periods are for instance recognized as undesirable investment positions as the expected income stream is insufficient to repay an investment during an adequate time period (Remer and Nieto 1995). As Remer and Nieto (1995) put it, should the amount of time required for the project to pay itself be prolonged, the investment will not be worth undergoing.

The method is similar to the IRR procedure, only that the unknown variable is changed from interest rate to years, and that all of the future cash flows are not considered (Remer and Nieto, 1995). Instead of wanting a high discount rate a manager desires a minimum payback period. The measurement is calculated by performing the following computation:

$$Payback\ Period = \frac{Initial\ Investment}{Cash\ Inflow\ per\ Period}$$

3.3.4 Disadvantages of payback time

This measurement has as well certain drawbacks that need to be considered. First, the payback rule ignores all cash flows after its cutoff date[2]. The consequence will be an automatic rejection of any project with long payback rate, even though it might be more profitable. Second, it gives equal weight to all cash flows before the cutoff date, even though this implies different values of NPV (Brealy et al, 2011). The conclusion will thus be to have a strong emphasis on the appropriate cutoff date.

Other methods that are frequently used in measuring and rewarding investment performance include economic value added (EVA) and return on investment (ROI). The reasons for neglecting these measures in this thesis are the chosen focus on analyses that provide a 'least cost' alternative. Emphasizing on analyses that are based on earnings, individually negotiated, will provide inconclusive results that cannot be generalized to the industry in focus.

[2] Cutoff date: a designated limit or point of termination

4. Methodology

4.1 Research design

The research approach conducted in this thesis will work as a framework to analyze the attractiveness of LNG as marine fuel for the container vessel segment in the North European ECA. Broadly, this dissertation will focus on two investigation areas where the first area of focus will be the quantitative aspect of LNG as marine fuel and the second will be the qualitative view of LNG.

The derived result of the quantitative analysis will provide an objective conclusion to whether the source of energy may be viable or not in an economic sense. As this quantitative fashion of viability is an important factor for ship owners when regarding the adoption of any innovation (W&W, 2013) such a mathematical analysis will present the initial understanding of the possible prosperity of a novelty. The second objective is to examine theories that enable to explain the potential feasibility of LNG. In contrast to the investment calculation these theoretical models will not provide a yes or no answer but rather discuss both the advantages and disadvantages of the abatement strategy in focus. As a result, it will offer a more extensive explanation to why any strategy is feasible or not to implement in a feeder vessel. Together, these methods will offer thorough insight of the essential requirements that needs to be in place for any abatement system to thrive as the main strategy for the shipping industry.

4.2 Research strategy

This thesis will undergo an exploratory study to generate insights and better understanding of a relative new phenomenon, and will accordingly assist the overarching objective of this dissertation to reveal the viability and feasibility of LNG as a propulsion fuel. The exploratory research approach will be helpful in conducting a thorough investigation of a topic and to gain a qualitative understanding of the underlying reasons and factors affecting a chosen subject (Robert A. Stebbins, 2008). I will because of this perform a case study to discover any reasons behind an event, and emphasize on a contemporary phenomenon in its real-life context (Blumberg et al. 2005).

The methodological approach outlined in the following sub-section aims to study LNG as marine fuel in a holistic fashion, by using a mix of empirical information gathered through both primary and secondary information. This information encouraged me to characterize the previous research as somewhat incomplete, as they discuss the various abatement strategies without regarding the aspect of LNG as a new fuel standard. For that reason, I will endeavor to disclose the feasibility of LNG as a new disruptive abatement technique with focus on the container segment.

As mentioned, this thesis will be rooted in a single case study on different abatement strategies. It will elaborate on the various challenges these different techniques may face and reflect real-life predicaments that are likely to happen. Even though some might say that case studies are hard to conduct, and that it often is influenced by a biased researcher that impedes any generalization, it is a good method for getting a rich picture and gaining analytical insights from a research study (Thomas, 2011).

4.3 Research method

For an optimal support and clarification of the thesis question I will employ a mixed method study based on both quantitative and qualitative research approaches. Such a research method has been selected due to its ability to develop insights of a phenomenon that could not be understood using only one of these research methods alone (Saunders et al. 2007). This entails that my dissertation will be based upon an approach that includes both theoretical and numerical analysis of the chosen subject.

As the conclusion of this thesis somewhat rely on numerical responses, quantitative data becomes important. The overall objective of this research method is to test and compare different alternatives and clarify one particular issue: if any abatement strategy is economically viable or not in the shipping industry. This economic analysis will generate a direct answer to invest or not to invest, based on industry information. The quantitative research method has thus a positivistic approach to a phenomenon and is used to provide reliability with the ability to provide causality (Bryman, 1984). Moreover it generates objectivity to the dissertation by having distance between the observer and the observed.

The utilization of qualitative approach is also suitable for this thesis as it provides a flexible way to obtain complex contextual description of a given topic. It is different from the numerical approach in its way of generating specific information about different values, and can assist in gaining a rich and complex understanding of a particular phenomenon (Woodsong et al. 2005). The selection of this method stems from its flexible characteristics and that it enables multiple techniques to gather and to analyze data. Its importance can for instance be related to its way of collecting primary data that is otherwise unattainable to private individuals. One applicable source of primary information in this regard has therefore been through interviews with individuals from key players in the industry. The chosen interviewees have been selected based on their work position in companies connected to the container segment, and because these companies operate with the vessel size that is typically seen in the area**.** They are all managers in their respective companies and were preferred due to their industry knowledge in the N-E ECA and their opportunity to provide me with information on the future operational challenges for shipping companies. Their job position made them suitable candidates to answer my questions regarding the industry perception of the future environmental regulations in the area. Additionally, as I found it relevant to meet individuals related to environmental friendly engine solutions, Wärtsilä stood out due to the industry perception of it being the market leader for green power solutions. Furthermore, I believed the report could benefit from a governmental perspective. When considering the appropriate governmental organ I wanted one that is connected to the European Union in addition to publicly supporting environmental friendly actions in the shipping industry. The Danish Ministry of Environment was thus an appropriate choice based on its multiple reports on the subject. The report that covers the assessment of NOx emissions in the N-E ECA (2012) is one illustration of this. The overall objective when selecting interviewees was therefore to locate individuals with explicit knowledge in their specific field who additionally could provide me with trustworthy information applicable to my study. In order to capture their full understanding of the topic, the utilization of a semi-structured interview process was chosen. This structure allows for an open discussion around a topic with the toleration of both open and closed questions in addition to the possibility of posing new questions directed at the responses from the interviewee (Robert A. Stebbins, 2008).

Together, the utilization of both a qualitative and a quantitative part is thus a good way to complement the strengths of the two research methods without having any overlapping weaknesses. It will allow both statistical data and elaborative explanations which will result in a validation should they provide the same result, and provide an explanation of the differences should they be dissimilar (Johnson et al. 2004).

4.4 Data construction and sampling

The information gathered to support and facilitate this dissertation consists, as mentioned, of both qualitative and quantitative data, and can be divided into both primary and secondary information. This direction of data sampling has been determined due to the limited information readily available for private individuals on the chosen subject. The best way to obtain the required information was thus to meet key market players in person, in addition to the utilization of the secondary data available at hand. The secondary data used in this paper has mainly been gathered from reputable organizations such as IMO, Lloyd's Register (LR), and Det Norske Veritas (DNV) which all were selected due to their well-informed reports and high standing in the shipping environment. When the information gathered did not suffice the intended use, the secondary option has been Google Scholar and EBSCO. Additionally, to locate specific knowledge that were not present in neither of the types of sources mentioned, I chose to examine various company web-sites in areas of their specialization. The quantitative section of the secondary data is derived from Bloomberg in order to apply accuracy in the calculated analyses. The opportunity to obtain information from these sources was made possible by the Copenhagen Business School and their computer labs.

As this report fronts the European market it will refer to the standard of Brent Crude Oil whenever discussing the development of Heavy Fuel Oil (HFO). Although its price, along with the alternative of MGO, publically is denominated in USD per barrel it is collected from Bloomberg as USD per metric tonne (MT) to better compare it to the energy of LNG. When considering the natural gas, this study will use the price obtained from the National Balancing Hub (NBP) due to its historical position as a pan-European benchmark (Patrick Heather, 2012).

Primary data has also been a requisite throughout this study. Its necessity, in particular, proved to be vital when analyzing the various abatement strategies where the initial data was insufficient or not present online or in books, reports, or articles. In this regard, it turned to be imperative when assessing the individual contribution of an abatement strategy to ship owners. The chosen method to obtain this information was through interviews with individuals who had knowledge through their job position and particular field of specialization. The specifics around various engines, vessel of focus, and other numbers used in the mathematical analysis demonstrates this necessity. Combined, the primary and secondary data will act as essential inputs when discussing the overarching question of this study.

4.5 Reliability and validity of empirical data

While reliability of the collected qualitative data focuses on the extent to which an experiment or test provides the same results on repeated trials, validity concerns of how well a researcher manage to measure what he intends to investigate (Carmines and Zeller, 1979) and if the researcher gains access to his participant's knowledge and experience (Saunders et al. 2003).

Even though the primary qualitative data, carried out in forms of semi-structured interviews, was conducted in a manner that ensured as much relevant and accurate information as possible, there is always the problem of generalization. The information extracted from the interviews might not be generalizable to all populations or applicable to other research settings (Saunders et al. 2007). Consequently, the interviews conducted in line with this thesis reflect the opinions of the interviewees at one certain point in time (Saunders et al. 2007), which then might change should the situation develop and new insight emerge.

The interviews conducted have not encountered any difficulties or concern regarding confidentiality or lack of interviewee expertise, which seem to be in line with the desired reliability and validity. However, when it comes to the section of analysis, I might risk threatening the aspiration of the objective stance when interpreting the primary and secondary data. I will nevertheless strive to be as objective as humanly possible and to critically interpret the information at hand.

Part II: Background

5. Background

5.1 Current situation

Since the days of ancient Egyptians, Greeks and Chinese, through the Islamic Golden Age and the Renaissance, philosophers and scientists have sought to make sense of the forces and processes of the natural world and humanity's place within them (Steiner, Global Environmental Outlook, 2012).

The last decades have revealed a growing concern that the human impact on the environment has reached a point that is irreversible. The fear has risen in line with the industrialization of the economy, and the ever increasing production of superfluous goods to silent the western hunger for materiality. The total consequences of human impact have reached a level where it endangers the world's sustainability, which currently is apparent in the recent change in climate and various ecosystems. The concern is profound, and the outcome is likely to be the loss of important parts of the oceanic ecosystem in addition to harming the local environment.

The pressing situation calls for the human population to take action towards reducing the amount of emission released. This has inspired multiple organizations and associations to form treaties around the globe to ban the release of pollutants, help endangered species, reduce the climate change, and to hinder global deforestation. However, in spite of all these establishments the change has not been large enough to set the world towards a new path, which has left the world on its current negative route. In this context, science has been thought to be the main driver to support a new policy development in implementing standards of abatement technologies. However, this has historically been difficult to accomplish, although barriers in the past have not been based on lack of adequate technology, but rather on shortage of political will to implement official agreements. Neither satellite observations, laser technology, fiber optics, nor other technological breakthroughs have been able to alter the negative spiral of the world. The present circumstance thus requires an integration of scientific discoveries with the unification of political effort in order to move the world on to a more sustainable path.

There has however, been several summits over the years, where the focus has been on the environment and its development. The first conference took place in Stockholm in 1972, which resulted in a resolution of 26 principles concerning the man-made impact on the world. As the years went by, new dimensions have been implemented, where the current number of objectives now tallies the total of 90 (UNEP). The need for resolution has grown to be acute, where effective measure needs to be taken. Not to prevent damage, because this point is already surpassed, but to create a limit to prevent any irreversible damage. As in 1972, the quest of these conferences consists of gathering the global strength to fight the challenges that lies ahead. Since the environmental situation is becoming increasingly unstable, it is with the outmost importance that summits like the Rio+20, and organizations like IMO and UNEP manage to gather global forces to unify the countries around new regulations. The agreement of emission control areas is an example of one of these regulations that is paramount for a greener development of the planet.

5.2 Shipping, Politics, and the Environment

The current situation mounts pressure on every potential polluter to adopt greener practices and to reduce its emissions. This is a thought shared by the European Union (EU), as it actively contributes to shape the environmental friendly future of the transportation industry. According to the Danish Maritime Authorities and its report from 2012, much of the EU funded support is centered on the Baltic region where the federal association assists in a large number of projects. Many of these federal operations clusters around the European transportation network integrating land, air, and sea, where one of the objectives is to establish a Trans-European Transport Network (TEN-T) for the mobility, economic, social, and territorial cohesion of the European Union (European Commission). The goal is to implement a way to allow the mobility of goods and people within the region as well as to focus on energy efficiency and the challenges of the environment. With this in mind, these factors are seen as essential to bridge the climate change challenges and the unification of international policies for a greener future.

The treaty of TEN-T has additionally paved way for the concept of 'Motorways of the Sea' in order to mitigate the difficulties in the transportation industry regarding congestion problems, environmental performance, and energy inefficiency. The environmental trouble caused by the industry, may largely be alleviated by a potential adjustment of the shipping industry, as it consists of 90 percent of the global trade (IMO, 2011). In this fashion, shipping is a prime facilitator for a better global future should its total emission be reduced according to the new regulations presented by the IMO. The key to success is a continued focus on the environment, the creation of policies that provide complying shipping companies with a competitive advantage, and the share willpower from companies to be guided by a sense of corporate social responsibility. Unfortunately, this is easier said than done as corporations tend to focus on short-term profitability to satisfy shareholders, and to act according to this primary duty. Shipping companies are thus more inclined to look for processes that lower the total costs simultaneous to being able to comply with updated regulations. Their main objective is thus not to a take leap as the frontrunner of a greener future but to rather act according to their minimum expectations in order to cut costs and to maximize profits (W&W, UF, Tschudi Lines, NCL, 2013). Having this problem in mind, The United Nations needed a governmental body to pay close attention to the global environment, its development, and the compliance of regulation by companies. In the regard of maritime industry they established an organization to develop and maintain a regulatory framework for maritime safety, security, environmental concerns, and legal matters. This organization was named International Maritime Organization and was established in 1958 (IMO).

5.3 Overview of the industry in the emission control areas

The type of marine fuel mainly used today is high-sulfur fuel oil (HFO) (Wärtsilä, 2013). It has been widely used for its positive effect as propulsion energy, but has simultaneously a negative outcome in its way of producing pollutants. When burned it emits substances like SOx, NOx, PM, and CO_2 which cause damage to the surroundings. To put an end to this release, IMO have demanded a substantial reduction of the emission of such materials in addition to designate control areas where these substances will be diminished to a minimum. In this effect, IMO have historically put in place comprehensive sets of regulations to ensure ship-owners' conformity. The organization is continuously pursuing a proactive approach to reduce the pollution of ships and address their concern and sincerity in different directives (IMO). These regulations have mainly been instructed through the MARPOL Annex protocol where they announce the importance of preventing spill and emission of hazardous substances to the marine wild life.

As there are certain areas that have oceanographical and ecological conditions that are particularly vulnerable to excessive ship traffic, these regions have been defined as "special areas". These provinces have typically been recognized for their susceptible environment and have as a result drawn particular interest from the IMO where the organization emphasizes its concern by conducting higher level of protection. IMO has named these areas Particularly Sensitive Sea Areas (PSSAs) and has implemented specific measures to control maritime activities in these regions. One of these measures is the designation of Emission Control Areas where specific rules control the emission and discharge of vessels that sail in the region (IMO).

Although there are several ECAs around the world, this report will refer to mainly one, the one that has the most geographical proximity namely the North-European ECA. This region consists of sea areas such as the English Channel, the North Sea, including Kattegat and Skagerrak, and the Baltic Sea, which can be viewed in the figure below.

Figure 3: An overview of the North European ECA

Note: The directly affected countries are displayed in green. The shaded area indicates the partner countries of the study of Danish Maritime Authority. Source: Danish Maritime Authority - North European LNG infrastructure project (2012)

The environmental situation in the North European ECA has drastically worsened during the recent years (HELCOM, 2010). Its maritime traffic has risen sharply in volume and has grown to become one of the busiest shipping routes in the world (Kågeson, 2005), where more than 2000 ships operate in the area at any time (DNV Experience, 2011). The accompanied externalities of emission have multiplied accordingly and are now in a position that may change the marine ecosystem completely. Eutrophication is one illustration of the major concern, as most parts of the Baltic Sea shows clear symptoms of illness, except the northern parts of Kattegat and the Bothnian Bay. As the situation is heavily affected by nutrient pollution, a process driven by excessive exposure to nitrogen and phosphorus, there is growing importance of ship traffic to reduce its emission of NOx and SOx (HELCOM, 2010). The alarming shifts in the marine wild life and the harm of hazardous substances to living organism and bottom sediments in all parts of the Baltic are other ones. Especially when considering that the affected organisms form the baseline of the ecosystem of larger fish. Additionally, the predicament increase with the geographic element of the area which makes it nearly land-locked, with a consequence of low water exchange. This, alongside great shifts in temperature caused by the yearly seasons, makes the Baltic ecosystem particularly exposed to environmental impacts of humans. The situation has become so delicate that the urgent needs of measures are critical in order to save the oceanic environment of the Baltic Sea (HELCOM, 2010).

In order to fight the environmental battle, the IMO has assigned certain directives for compliance by the local marine industry. The main controlling protocol that directs rules and regulations concerning these maritime emissions was initiated through the 'International Convention for the Prevention of Pollution from Ships' – the MARPOL Convention (IMO). The convention is as of May 2013, acknowledged by 152 states which represent 99.2 percent of the world's shipping tonnage. It is a creation based on the issues discussed at the 1972 Stockholm Conference on global environment and surfaced due to the environmental challenges caused by the industrialization and world economic growth. The MARPOL Convention is one of the most important international conferences regarding maritime environment and has an official objective to protect the environment through the complete elimination of harmful substances and minimization of accidental discharge (IMO). It refers to these challenges in six technical Annexes. These annexes entered into force at different times throughout history, with the first implementations originated in 1983. The different annexes include (IMO):

Annex I: Prevention of Pollution by Oil (1983)
Annex II: Prevention and Control of Noxious Liquid Substances in Bulk (1983)
Annex III: Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (1992)
Annex IV: Prevention of Pollution by Sewage from Ships (2003)
Annex V: Prevention of Pollution by Garbage from Ships (1988)
Annex VI: Prevention of Air Pollution from Ships (2005)

In regard of this thesis, the latter annex, Annex VI - the prevention of air pollution, will be the one in focus as it is the last one to be updated and the one that will cause implications in the future for the vessels currently sailing in the chosen ECA. The objective for the emission reduction requirement was to be gradually implemented, and result in compliance from its implementation dates by the various ship-owners. The requirements can be divided in two categories: global requirements and requirements specially implemented in designated areas, the ECAs. The IMO Annex VI has been updated several times since its origination and has developed stricter legislations accordingly. Its main objective is to limit the harmful substances of Sulfur Oxide (SOx), Nitrogen Oxide (NOx), Carbon Dioxide (CO_2), and Particulate matter (PM). The principal amendments are the ones that (1) limit the sulfur content in bunker fuel to be of less than 1% in ECAs (July 1st 2010), (2) the limitation of sulfur content to be less than 3.5% in all global areas (January 1st 2012), (3) the limitation of sulfur content to be less than 0.1% in ECAs (from January 1st 2015), (4) and the one limiting the NOx level in ECAs to be 75% below the current IMO emission standard, the Tier II (January 1st 2016) (DNV, 2010).[3] Beneath is an overview of the regulation that needs to be followed after its date of enforcement.

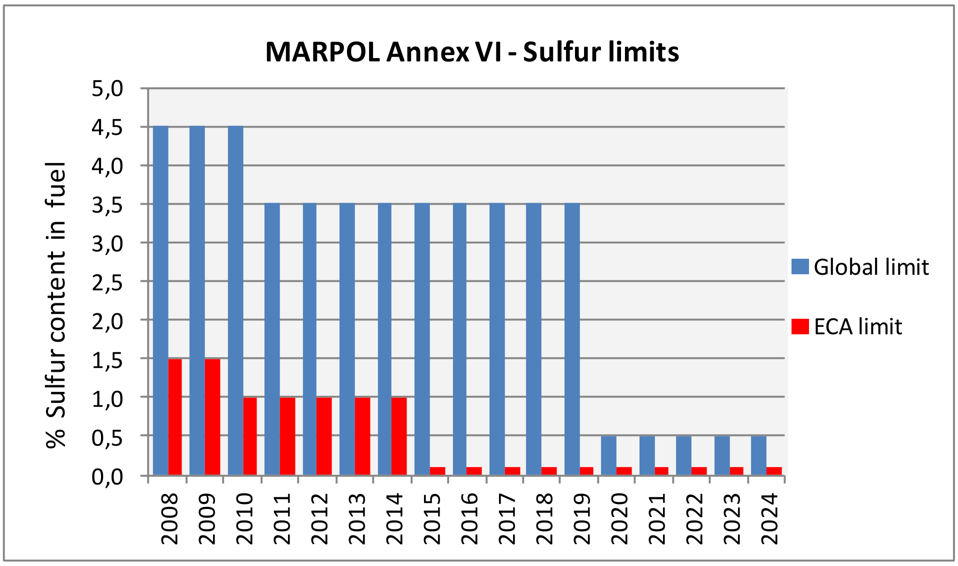
Table 1: MARPOL Annex VI revision - SOx

Sulfur limits for fuel oil	Sulfur content in fuel	Enforcement
Global	4.5%	Prior to January 1st 2012
	3.5%	January 1st 2012
	0.5%	January 1st 2020
ECA	1.5%	Prior to July 1st 2010
	1.0%	July 1st 2010
	0.1%	January 1st 2015*

* The sulfur content of 0.1% also applies to all EU ports and inland waterways from 2012 (EU Directive 99/32 Amendment)

Source: IMO

Figure 4: Revised MARPOL regulations on SOx



[3] The regulations concerning the sulfur content is targeted both those currently operating and new ships, while emission regulations regarding NOx are target towards new-builds only. This latter regulation may notably be postponed to 2021 due to pressure from some of the Baltic states (GLE, 2013).

Table 2: MARPOL Annex VI revision – NOx (*Source: IMO*)

Nitrogen limits for fuel oil	Nitrogen content in fuel			Enforcement
	rpm < 130	130 ≤ rpm < 2000	rpm ≥ 2000	
Tier I (Global)	17 g/kWh	45 x rpm-0.2	9.8 g/kWh	January 1st 2000
Tier II (Global)	≈ 20% below Tier I level			January 1st 2011
Tier III (ECA)*	≈ 75% below Tier II level			January 1st 2016

* Tier II standards will continue to apply globally after 01.01.2016, and will not be amended by the global emission cap

Additionally, there is excitement about the future choice of IMO to decide when the global cap of emission will be implemented. The ultimate obligation is to reduce the sulfur content in bunker fuel to 0.5% in all global areas, although the question is related to its implementation date to be either 2020 or 2025. This decision will be taken subsequent to an IMO review of the availability of environmental marine fuel in 2018 (IMO).

Ship owners have limited options to modify their vessels in order to meet the terms of regulation set forth by the IMO. Up to date there are currently four well known abatement technologies that prevent the emissions of SOx, NOx, CO_2, and PM. These are two different types of engine fuel and two different technologies that reduce these harmful substances to a minimum. The fuel oils in mind are MGO and LNG, while the technologies with best recommendations are the exhaust gas scrubber technology and selective catalytic reduction system (SCR).

6. Ship owners' Compliance Strategies

To meet the terms presented in the MARPOL 73/78 convention, ship-owners that operate in the designated area do not have a wide variety of options available. The current market has only a few feasible alternatives even though experiments have shown various types of marine fuel to function as well. In essence, the vessel operators in the North European ECA are left with three alternatives:

1. Switch to low sulfur gas oil (MGO) and SCR (SCR post 01.01.2016)
2. Continue to use HFO with exhaust gas scrubber and SCR (SCR post 01.01.2016)
3. Switch to burning Liquid Natural Gas (LNG)

Historically, the marine fuel market has consisted of different types of bunker oils[4], which has developed into different types of oil based marine fuel. Bunker oils can commonly be divided into two groups: residual fuel oil and distillates, where these classes again, often can be subcategorized

[4] The term Bunker is a reference to any type of fuel which is used as propulsion energy aboard ships.

according to their viscosity and blend. Viscosity is a measure of a fuel's resistance to flow, commonly denoted in centistokes (cSt), and distillate is a reference to the process where any substance or liquid mixture is separated by heating it to a certain temperature and where the rest is condensed as steam. Although there exist different types of oil based fuel, like the ones mentioned below, this report will mainly refer to heavy fuel oil whenever discussing the fuel oil used today:

- Heavy Fuel Oil (HFO): It is the most economic option for any vessel owner. It is a non distillate and close to being a pure residual oil. It has a high viscosity of 380 cSt or above and requires heating in order to make it liquid enough to run through the piping system.
- Intermediate Fuel Oil (IFO): A type of marine fuel which is a blend of gas oil and heavy fuel oil which results in lower viscosity. This category can be divided by their classification of viscosity of either 380 cSt or 180 cst.
- Marine Diesel Oil (MDO): Like IFO, marine diesel oil is a blend of HFO and gas oil. It has however more gas oil than IFO which results in higher viscosity of up to 12 cSt.
- Marine gas oil (MGO): A pure distillate and not a blend of residual oil.

6.1 Marine Gas oil

Of the different compliance strategies mentioned above, the option to change the marine fuel to ultra -low sulfur fuel oil is the one that will be the easiest. In this study, MGO will refer to the marine fuel which contains the adequate amount of sulfur to satisfy the SECA-requirements post 01.01.2015 (<0.1%). It is similar to automotive fuel in its functionality, causes no major modifications or adjustments on the vessel or the engine, but will however have one major drawback. As of now, MGO's expected demand will likely exceed its supply which consequently will end in a supply shortage after 2015. As a result, this will cause MGO to be the most expensive marine fuel on the market. According to the technology company Wärtsilä, a producer of environmental friendly solutions to the marine industry, they estimate that MGO will have a future price premium of 50% of HFO, which consequently will increase the fuel costs for ship owners massively. Accordingly, this will increase the factor which already is the biggest single cost for vessel owners and cause concern for its long term utilization (Remi Eriksen, DNV 2012). For that reason it is likely to act as a short-term strategy and work as an attractive approach to a "wait and see" strategy.

6.2 Exhaust gas scrubber technology

Exhaust gas scrubbers, known as the open loop scrubber, is a technology that removes sulfur oxides and particulates from the exhaust gas. It is a technology that enables the continued use of HFO and consequently the same ship engine, although there are needed significant alterations on board. It consists of three main procedures where the gas from the engine initially enters a scrubber tank where it is mixed with sea water. Subsequently, the wash water is directed through another treatment tank where the waste will be separated from the cleaner water. Then, the waste enters a sludge tank to be securely contained, while the residual water gets sprayed with fresh water mixed with caustic soda (NaOH) to become neutralized. The residual water is now clean enough to be discharged safely back into the ocean (wartsila.com). Should this be a closed loop scrubber system, the technology would involve a circulation of the wash water, instead of using fresh sea water for every circular turn. A hybrid approach enables the closed loop process whenever this is needed, i.e. inside ports, and the open loop when sailing at the larger seas (Hamworthy.com).

6.3 Selective Catalytic Reduction technology

After 01.01.2016 the use of MGO and HFO with gas scrubber technology will however not be sufficient to comply with the regulations inside the ECAs. The reason is that these systems only cleans the sulfur content of the fuel and neglects the purification of nitrogen oxide. In order to meet the regulation in 2016, the minimization of NOx has to be considered as well.[5] The prime technology system utilized to take care of this production of NOx is the advanced catalytic after-treatment system, a method also named Selective Catalytic Reduction technology (SCR). This system treats the exhaust gas with ammonia or urea and directs the liquid substance through a catalytic converter at temperature 300-400 degrees Celsius. If burned at the right temperature, the unwanted nitric oxides are reduced by more than 80% and the by-product, such as the oxidation of sulfur dioxide, is suppressed. The result is that the predicament of NOx will mostly be resolved and be well within the limits of ECA presented by the IMO (hamworthy.com).

6.4 Liquid Natural Gas

The third alternative is to use natural gas as marine fuel. LNG is simply natural gas, predominantly methane, which is transformed into liquid form at very low temperatures (around -162 degrees Celsius). When liquefied, the gas achieves a high reduction in volume, to a density of 1/600th volume of its gaseous state, which makes it very efficient to transport, and consequently creates the possibility to cut transport costs significantly. Its liquid form has mostly been used to carry the commodity from one port to another, where it at destination, is re-gasified and distributed through pipelines for both residential and industrial use (EIA).

[5] There is however ambiguity of the implementation date of the Tier III rule due to the proposition of postponement from Russia (Ministeriet, 2013, shippingwatch.com). An update on this decision will come in the spring of 2014, although industry players believe the EU will implement the regulations no matter the final decision of IMO (Wilhelmsen, 2013).

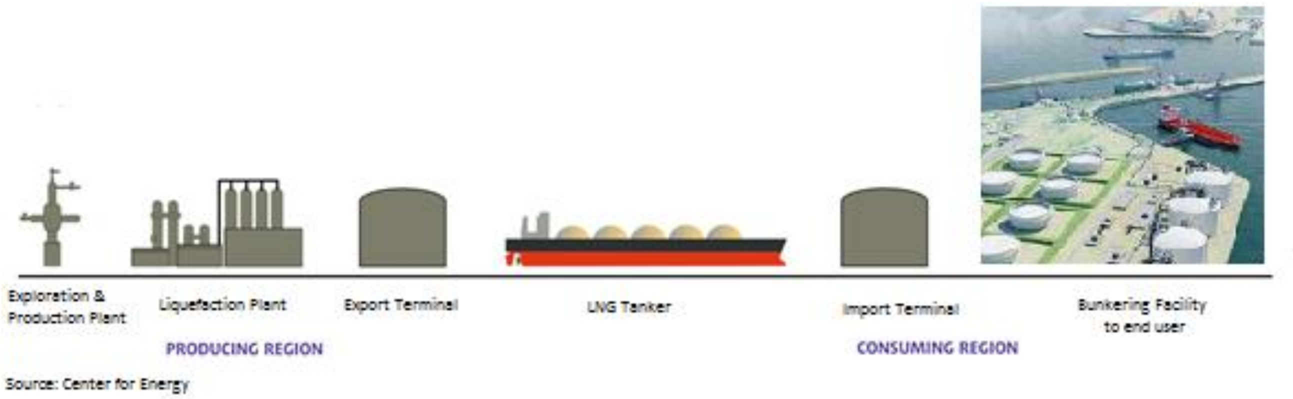
Although its advantages in the transportation segment are apparent, it has also proven considerable benefits in its use as marine fuel. One of LNG's most attractive competences in this regard is its potential to significantly decrease emissions because of its clean characteristic form. Additionally, it is an abundant resource worldwide with high energy content which, together, increases both its potential availability and concurrently decreases the fuel consumption. This creates an opportunity to reduce fuel cost considerably in comparison to using other fuel oils when new regulations enter into force in 2015 and 2016.

7. LNG supply chain

7.1 Up-stream LNG supply chain

The LNG value chain consists of 4 main segments that are highly interlinked. It starts from the exploration and extraction of its natural gaseous state and ends in the actual distribution to the final consumer in bunkering facilities as an energy fuel (Center for Energy Economics). Its pathway from being a hidden diamond, rough around the edges, to a vital power source can be viewed in the picture below.

Figure 5: The LNG value chain



7.1.1 Exploration and production

Natural gas has a start in the exploration and production which is an activity that ranges from the discovery and development of gas reserves, to the acquisition of adequate capital for supporting the drilling, and finally to the ultimate production. One part worth mentioning is the geologic risk that comes with this production segment. There are no guarantees that the area of interest contains sufficient quantity of natural gas, or that it exists in conditions that favor successful extraction.

The countries that have the largest gas reserves, and accordingly have the major exploration and production plants, are at current date Iran, Russia, Qatar, Turkmenistan, and United States, respectively and in that order (BP statistics). The total gas reserves are, by the end of 2012, proven to tally 187.3 cubic meters which is enough for about 56 years of global production at current rates (Reuters). However, gas reserves in some countries are still a state secret. And as this order of countries is based upon the published data from these nations only, the global gas reserves mentioned are therefore not to be perceived as 100% accurate.

7.1.2 LNG Liquefaction

The liquefaction process entails cooling the clean gas, removing any contaminants that might damage equipment, and preparing the resource to meet pipeline specifications at delivery point.

7.1.3 LNG Tanker and Import Terminals

The result of the major production capacities being located outside European borders creates the necessity for LNG to be shipped to large import terminals in Europe. The long distance between the production sites and the market prohibits the gas to be transported through pipelines which consequently requires the gas to be shipped with LNG tankers. These tankers are specially designed to keep the gas at atmospheric pressure and at cryogenic temperature (-162 °C) to sustain its liquid form. The LNG tanks are circular to best preserve the pressure in addition to it being especially isolated to prevent leakage or rupture in an accident. To simplify it further, the storage room is a tank within a tank to keep the energy source in a certain form (Wärtsilä, 2013).

The import terminals accommodate the ships and arrange for the distribution of the power resource to its final destination, whether it being for industrial and private use or for transportation fuel for trucks, buses or marine fleets. Depending on the final utilization it will be stored in a specific way and potentially be re-gasified and transported through a pipeline system on land.

7.1.4 Bunkering facility

The bunkering facilities and the import terminals are the most essential infrastructure to be built in the N-E ECA. It should contain different bunkering solutions and have the sufficient space to accommodate several of ships at the same time. Additionally, the terminals should provide the possibility to supply both industrial customers as well as marine consumers. This importance relate to the issue of exploiting economies of scale to keep the bunker price at a reasonable level (IMO, 2012)

A collaboration of the Scandinavian countries and several large energy companies have together with the Danish Maritime Authority (DMA) collected information for a major project concerning the establishment of an LNG infrastructure. Their result, published in DMA's report (2012), contained the following sites of existing, planned, and proposed LNG facilities.

Figure 6: Planned and existing LNG terminals

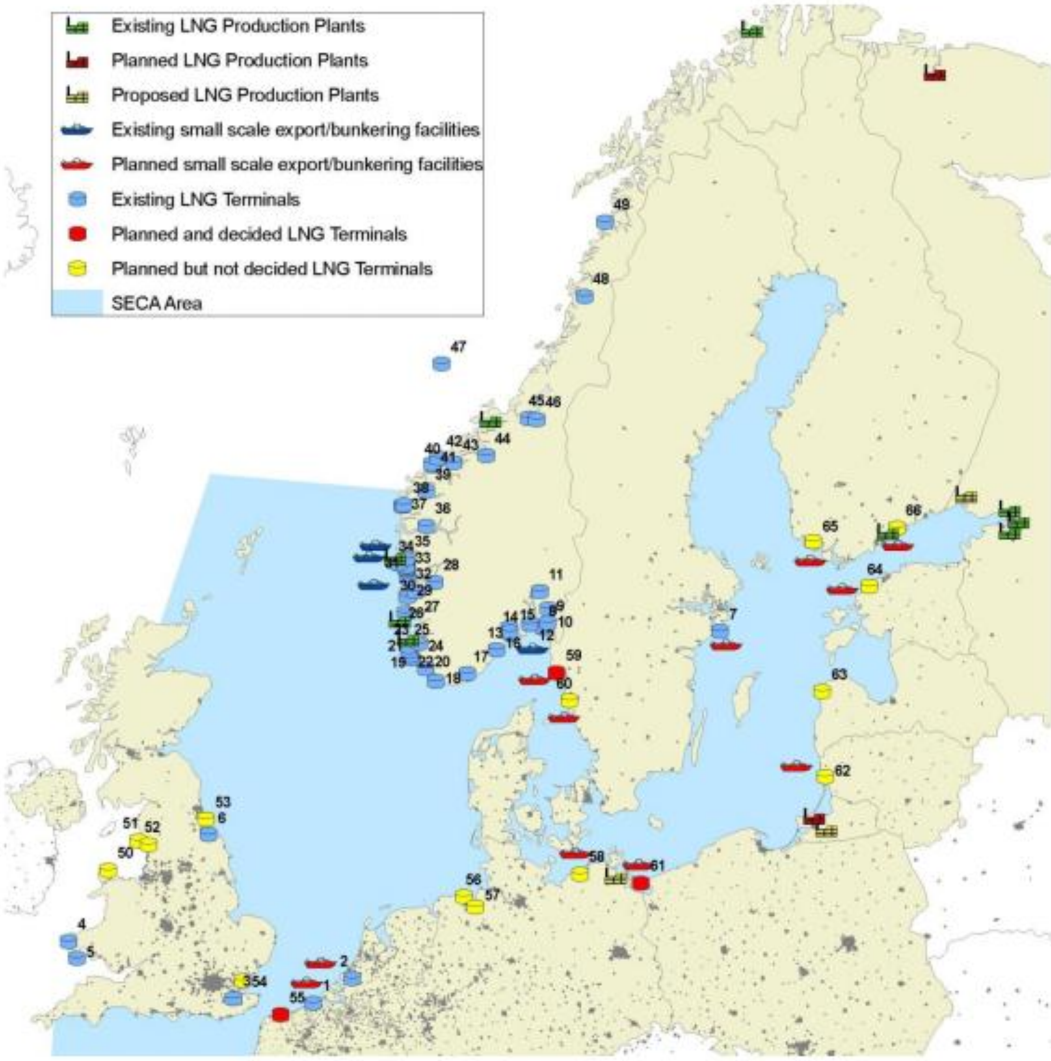


Figure 1: Existing, planned and proposed LNG terminals and productions plants
Source: Gas Infrastructure Europe, 2011, Gasnor, Gazprom. Note: Gazprom's proposed production plants will be either in Vyborg or Greifswald.

7.2 Critical port criteria for LNG bunkering

As bunkering facilities and ports have dissimilar requirements they will follow the variations of market demand and diverse environmental restrictions. This section will, accordingly, map the different factors to take into account when designing a port accommodating LNG as marine fuel.

7.2.1 Market criteria

Naturally, as in regular business cases, ports will be affected by market changes and the developments of the industry. Accordingly, these changes will affect the volatility of port activity and hence its economic viability. As a result, various parameters have to be considered before its establishment. Reflections on size of the terminal, physical attributes, and expected marine traffic will be some of the first factors to consider. In this respect, a port will have to plan its physical location with the potential capacity and port layout, in addition to the distance to competing LNG bunkering providers. Furthermore, a port will have to contemplate the required bunkering volumes for storage and distribution frequency, suitable bunkering solutions, and rules and regulation regarding safety and environmental aspects (DMA, 2012).

7.2.2 Economic criteria

The significant costs related to LNG infrastructure will guide the financial strategy of a port. This economic aspect will logically be one of the main features to consider when designing a terminal. One factor important to take into account is the investment cost, for instance in the form of constructing the quay and how this venture should be financed. The question of funding is often raised in the early beginning of an LNG project and has a relation to the infamous chicken and egg quandary of LNG. It is an illustration of the sticky situation between infrastructure and demand where infrastructure has to be present in order for demand to surface, or vice versa. It is a rather complex matter where both the current customer demand and banks' knowledge for judging economic feasibility is low, and where the LNG market itself is uncertain due to its infancy as marine fuel. The consequence may be low consumption of the resource and difficulties in obtaining financial support to fund projects. Although no-one question its potential, this uncertainty is a factor that affects the development of new LNG bunker terminals. Another variable to consider when creating the strategy of port establishments are the operational costs, like maintenance and personnel costs. These costs can be vital for the viability of the port, in addition to setting a base line for the LNG price. Additionally, they have to contemplate port fees and fairway dues (DMA, 2012).

7.2.3 Technical criteria

Technical aspects of port criteria are elements that are more detailed, with descriptions on of *how* an activity should be done, and the physical requirements relating to each action. These criteria include the physical instruments used for bunkering activities involving the proper solutions and dimensions suitable for different vessels at quay and the technical requirements relating to the vessel's access at the jetty.

7.2.4 Safety criteria

There is also a safety criterion that needs to be considered. Center for Energy Economics (CEE) state that the LNG industry so far has had an excellent safety record, and claim that this testimony is achieved through technical and operational advances assisted by engineering practices, operational procedures, and technical competency of personnel. Secondly, the standards, codes, and regulations that apply to the LNG industry are further factors that ensure its safety. The security is for instance covered by four layers of protection where the first layer involves the use of appropriate materials for LNG containment. The next layer is called secondary containment which contains and isolates any spills or leaks should the primary containment not hold. Safeguard systems is the third layer of protection which assist in minimizing and mitigating the effects of any potential release, while the forth layer of security involves the distance of an LNG facility to any public areas (Institute for Energy). Due to the perception of LNG to be a green and clean concept, safety and staff training requires high attention. In such a context, awareness of LNG handling, the location of LNG tanks, safety zones, and emergency actions are requisites to avoid accidents and LNG spills.

7.3 Bunkering solutions

This section of the paper will feature three different bunkering solutions for merchant vessels at quay. The usage of these different solutions is determined depending on the characteristics of receiving vessels as well as the traffic intensity, frequency, LNG tank volume, port infrastructure, and safety.

7.3.1 Ship-to-ship (STS)

One way to fuel a ship is by utilizing a bunker vessel at quay or at sea. The operation will be performed having the two vessels located alongside each other which allow fueling during sailing or at barges or ports. According to the DMA report (2012), ship-to-ship bunkering is highly flexible allowing all kinds of ship to be served, for high loading rates at each time, and at various locations. For these reason it is expected to be one of the major bunkering methods in the future. However, the procedure is restricted by heavy weather as this both complicates and creates unstable fueling process. The likes of strong winds, waves, current, and ice will all contribute negatively to this practice. Another downside is the large initial investment of a bunker vessel. Additionally it is built to serve only one purpose which raise the question of alternative occupation should LNG bunker demand be limited.

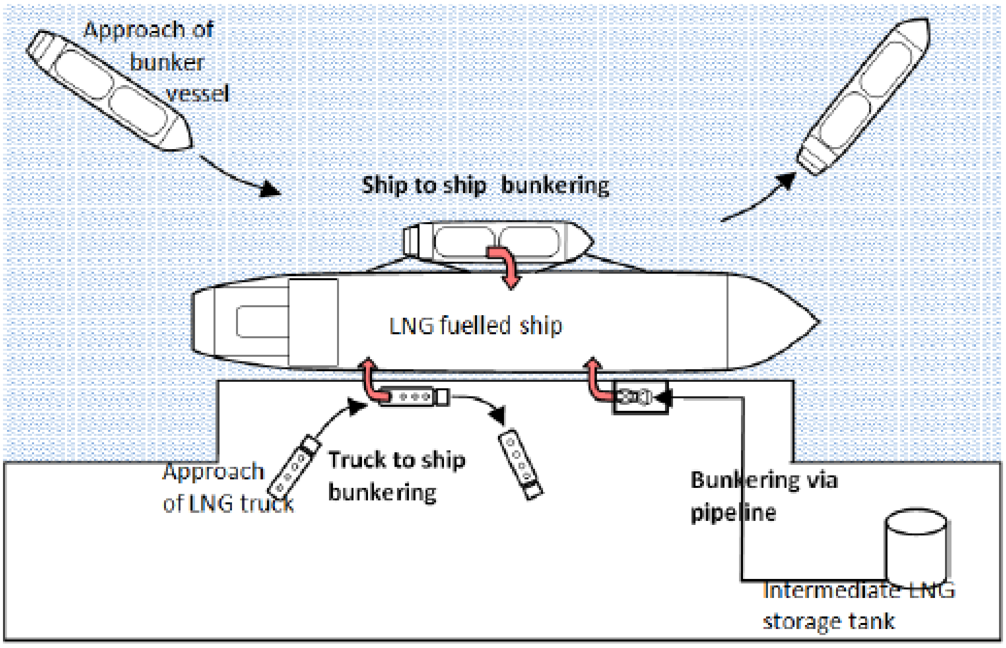
7.3.2 Truck-to-ship (TTS)

Truck-to-ship depicts a fueling method for LNG transfers of small LNG volumes from trucks at land. The emphasis on small LNG transfer is put due to the small truck capacity of LNG which varies from 40-80 m^3 of LNG (DMA, 2012) or around 25 tonnes of LNG depending on truck capacity, transport regulations, and road infrastructure (SSPA, 2012). The benefits of this procedure are however the inexpensive investment compared to other alternatives which make TTS bunkering a good initial bunkering solution. The downside reflects smaller volume transfers, or larger time at ports should the fueling volume require numerous truckloads.

7.3.3 Pipeline-to-ship (PTS)

Pipeline connections facilitate a way to transfer larger volumes directly from an intermediate LNG tank. The solution is flexible in its way to provide both low and high loading rates of LNG where the latter enables short bunkering time. One limitation is the technical and operational challenge with long pipelines. This requires a storage tank that has a fixed location with proximity to where the bunkering operation takes place. In turn, this can obstruct needed space for safety measures and other essential activities needed at dockside. In practice, these three solutions will look like the following illustration.

Figure 7: Three types of bunkering solutions: *Source: IMO, 2012*



Part III
Case study: Will LNG be viable as a marine fuel?

8. Quantitative analysis

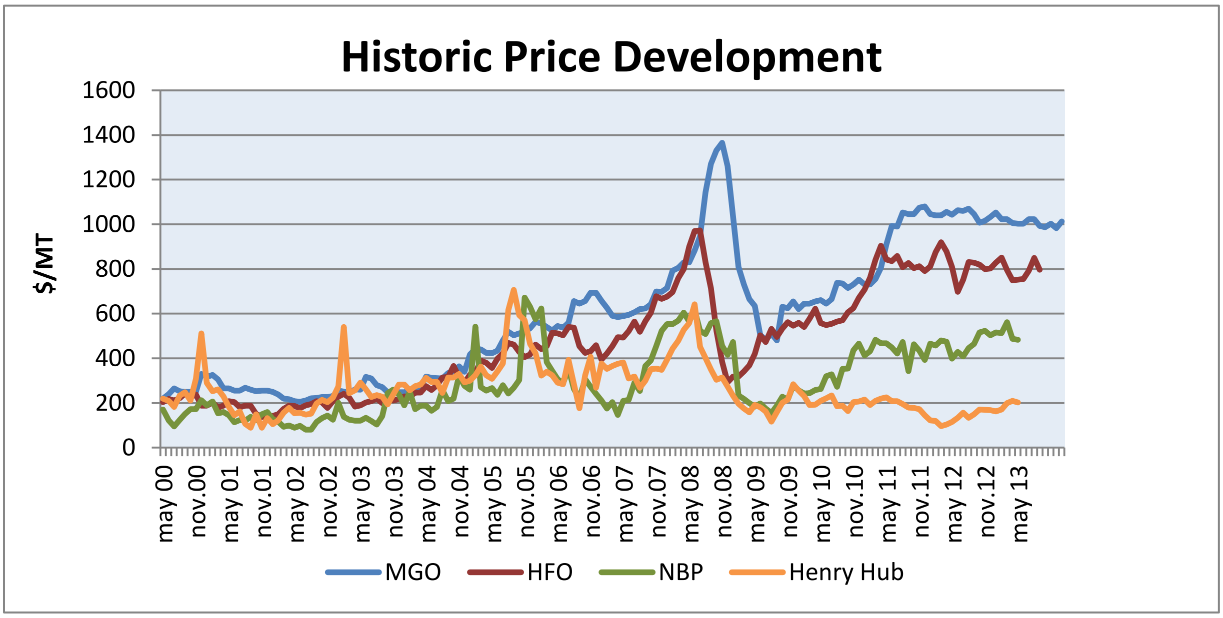
8.1 LNG availability and price

As the main focus for vessel owners is to sustain profitability (Tschudi Lines, UF, WW, NCL, 2013) the potential viability of LNG as marine fuel depends heavily on its availability and price. The minimum requirement for LNG is thus to have an equal price level as the current conventionally used fuel oil. An additional obligation will be to have a global LNG price instead of the current local ones that fluctuates with local demand, supply and regional events. One illustration in this regard is how the current prices vary from 4.2 $/MMBtu in the U.S., 9.9 $/MMBtu in Great Britain, and 16.06 $/MMBtu in Japan (Bloomberg with May 2013 prices and ycharts.com with prices from June 2013). These price differences may largely be explained by local demand and supply, the locally selected gas linkage to competitive fuel oil, and happenings like the nuclear accident in Fukushima in 2011. However, a stable and low LNG price worldwide can only come from a global gas index as well as high fuel availability and an increased LNG infrastructure around the world (IMO, 2012). The ultimate objective should also be on an efficient utilization of the resource where various industry players ought to co-use the LNG infrastructure to minimize the total cost. Consumers such as power plants, refineries, local gas grids, and the like, could in this context collaborate to provide large LNG consumption as efficiently as possible.

8.2 Historic price development

As one might see in the graph below, there has historically been a tight linkage between natural gas and crude oil prices up until July 2005. Gas prices have normally been lower than crude oil prices but have mainly followed the same trend and development. However, there has been an increasing price divergence in the later years, where the correlation has turned to be rather negative - the prices for petroleum increased, and the price of gas stabilized, or even declined.

Figure 8: Price development of different fuel oils



Source: Bloomberg and Reuters

When contemplating the price of LNG it is necessary to take into account the lack of a global price index. The result of this deficiency is the price difference of LNG depending on the region and market, where it is at its priciest at Asia, somewhat cheaper in Europe, and at its lowest in the U.S. This can be illustrated in the graph above as the large availability of shale gas in America force the local price to be significantly underpriced relative to Europe. However, it is important to have in mind that the observed price in any gas index is insufficient to represent the potential market price of LNG. In order to obtain the price of LNG one need to add the costs of distribution and liquefaction, and the like. In that regard, elements such as costs for transport, storage, loading, and cooling should be added to the hub price. The consequence will result in an added price that reputable organizations has estimated to be around 4 $/MMBtu[6] (GL-Man, 2012) or around 200 $/MT when using the conversion rate of 48.7 (unitjuggler.com). This thesis will because of this, also use this price premium.

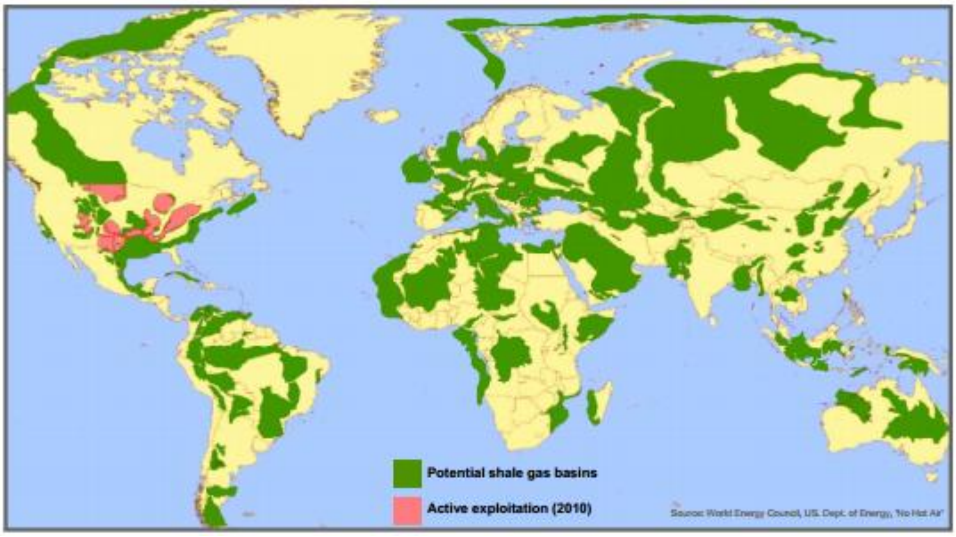
8.3 Future price projection

Although it is difficult to forecast the near- to medium term development of bunker fuel prices, there are some influential factors that can be identified. The future regulation of IMO to restrict the use of bunker oils with sulfur content above 0.1% will cause bunker fuels with *high* sulfur content to *decrease* in price, and bunker fuels with *low* sulfur content to *increase* in price. In this regard, the industry is likely to see the price of MGO to go up in relation to HFO which likely will remain stable, or even decrease in the long run. The LNG price is however fairly more complex to predict, due to its

[6] It is assumed that these distribution costs do not increase over time

novel entry in the industry. In this context it depends on the future demand of LNG and thus the proportion of ship owners who make the fuel switch. LNG availability, the materialization of infrastructure, the potential of a global gas price index, and the potential outcome of the standards war between petroleum and natural gas are other factors vital to consider. In addition to the aforementioned factors, the individual fuel oil will be influenced by competing fuel prices, future complementary equipment to run on gas, and finally the overall demand of shipping activities. Due to the many variables to take into account, any precise prediction of the future fuel prices is therefore impossible. Nevertheless, there is a possibility to identify certain key factors that likely will influence the price development of bunker oils. The price divergence between oil and gas may be expected to stay the same or increase in the future. This factor will be driven by the fact that the global natural gas reserves are larger than the oil reserves, in addition to natural gas being more evenly spread out. This global distribution of gas reservoirs can also create a massive price competition which consequently can force the gas price to remain at a low level. The potential foray of cheap North American shale gas may be one illustration of such a prophecy. Furthermore, as natural gas has the characteristics of both being globally abundant as well as globally dispersed it may cause a more stable price development in the future.

Figure 9: Potential and active global gas basins (DNV Experience, 2011)



Additionally, there will be a heightened demand for low sulphur fuel oil which will increase the price for MGO in comparison to HFO. When presenting the price forecast for the various fuel oils this thesis will utilize the forecast made by the renowned UK Department for Energy and Climate Change (DECC). Like their report, this thesis will portray three different scenarios: one low price scenario, one central price scenario, and one high price scenario. However, as DECC only presents the estimation of natural gas and crude oil, this dissertation will perform its own a price estimation of MGO.

Estimating future MGO prices

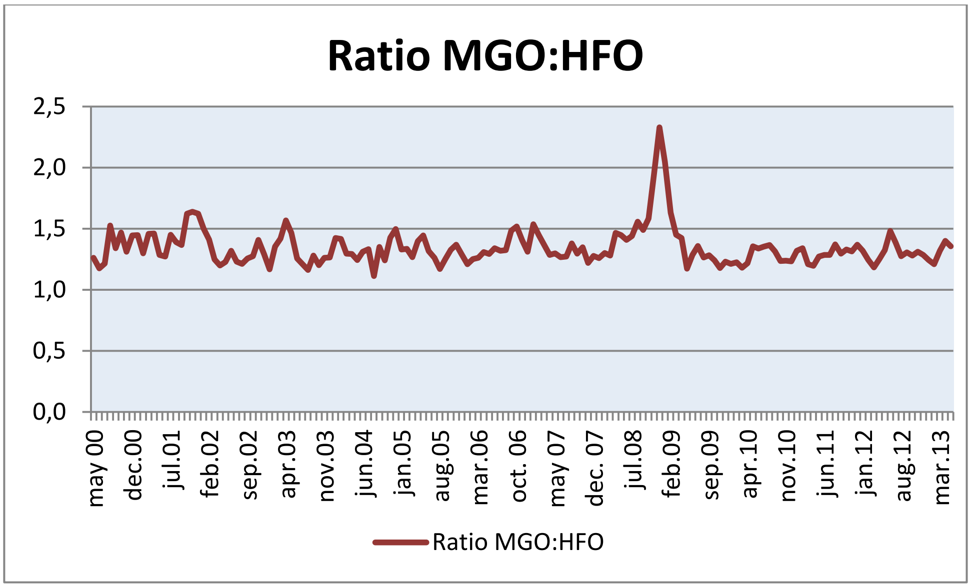
Based on my historic values of the prices of MGO and Crude Oil, which dates back to May 2000, this thesis provides a calculation to demonstrate the price correlation of HFO:MGO. From using the Pearson's r computation the following correlation factor was obtained:

Table 3: Degree of correlation between HFO and MGO

Fuel 1	Fuel 2	Level of correlation (0-1)
MGO	HFO	0,8517

Since the fuel prices correlate and knowing that relative prices are important in the analyses of abatement strategies, it can be valuable to demonstrate how the price of MGO developed in the last decade relative to the price of HFO.

Figure 10: MGO price relative to HFO price



To forecast an accurate future MGO price, this report will base its result on the historical correlation factor as depicted in table 3. From the figure above and the average price ratio of MGO:HFO during the last decade, a future price level of MGO is assumed. While the average price ratio was 1.3, this price level would not adequately reflect the future price development of any low sulphur fuel versus high sulphur fuel. As discussed above, new emission standards will increase the demand for low sulphur fuel oils as it allows ship owners to use incumbent engine technology without conducting any ship adjustments for avoiding emissions. To keep using the historic ratio of 1.3 will for that reason not suffice. This dissertation will because of this utilize a price ratio that gradually will grow to 1.5, a ratio that will represent a moderate increase in the MGO price relative to the current HFO price.

This dissertation has also focused on using the annotation of metric ton (MT) whenever comparing the different fuel oils. The importance of having the same denomination is because the fuel oils are different in density and have dissimilar energy content. The rate used to transform 1 barrel of oil to 1 MT is 0.1364 (unitjuggler). The rate used to transform 1 MMBtu to 1 MT is as earlier mentioned, 48.7 (unitjuggler). All the data beneath is obtained from the database of Bloomberg.

Figure 11: Price development of natural gas

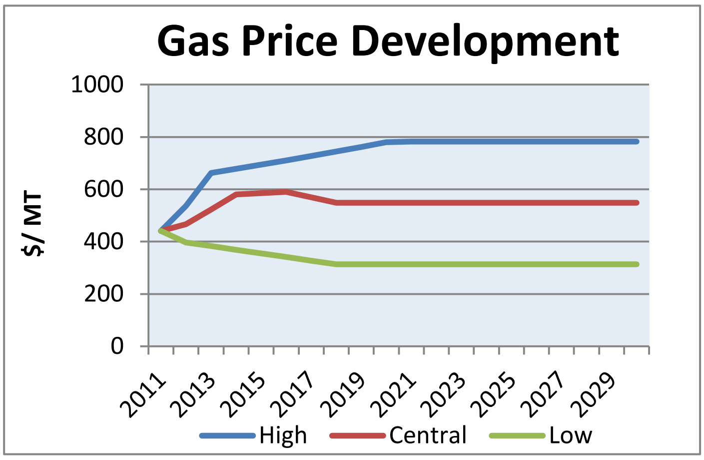


Figure 12: Price development of HFO.

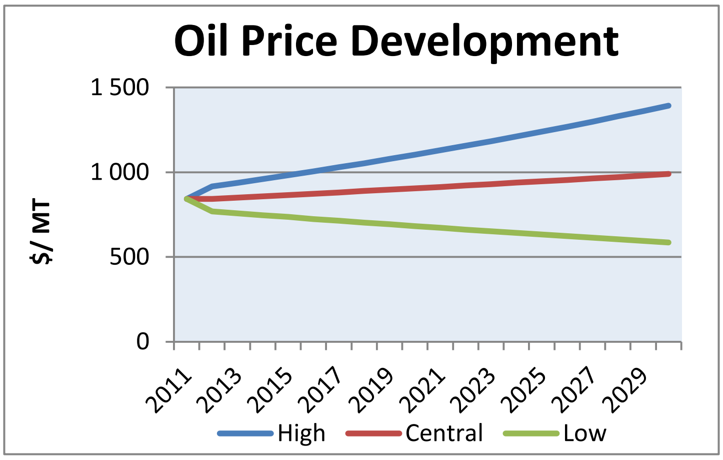


Figure 13: Price development for MGO

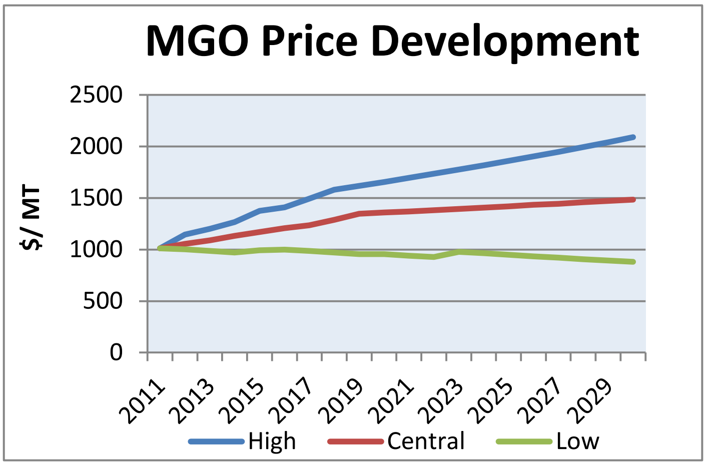
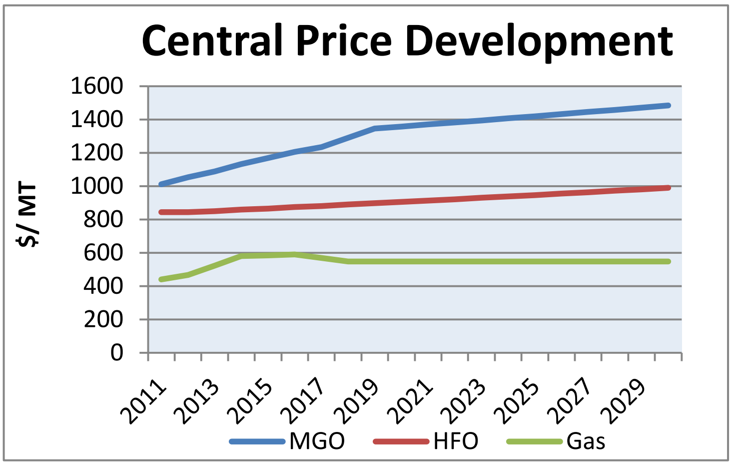


Figure 14: Central price development



8.4 Maritime LNG demand from new-builds

There are several things that need to be accounted for when calculating the likely demand of LNG. The principal factor to address is the establishment of sufficient LNG infrastructure to supply the marine market. Subsequently, when this is accomplished, other aspects rise to become equally important. The elements that strongly influence LNG demand will then be the availability of LNG, the competing compliance strategies (section 6), the relative capital cost of building LNG-driven vessels, and the price in relation to its competitors (section 8.2 and 8.3). The relevant numbers to these various factors are presented and discussed in the feasibility study in section 8.4.2.

8.4.1 Vessel of choice

Different ship types have dissimilar characteristics which make them more or less suitable for LNG propulsion. Some traits distinguishes themselves more than others as form and shape of the vessel, type of cargo, and type of trading pattern which could be either locally, globally, or a mixture of the two. I have however chosen to analyze the segment of container vessels only, where I have selected to study a classical feeder ship that operates 100% in the ECA. In line with this strategy I wanted to focus on a vessel that carries in between 1000 and 1500 TEUs. For that reason I chose "Aalderdijk" as a vessel of reference. A thorough elaboration of its characteristics can be seen in appendix H.

8.4.2 Feasibility study on LNG as marine fuel

This section will discuss the viability of LNG from an economic stand point. It will elaborate on the delimitations of the analysis, the different factors used, and the calculus itself. The analysis is based upon the collaborative study of DNV and Longva et al. which dates back to 2008 regarding the economic feasibility of emission reductions.

8.4.2.1 Delimitations for the calculation

According to industry players interviewed in this report there is still uncertainty about the taxes ship owners can expect to receive should their vessels not comply with the ECA regulations. There are also difficulties in finding any description of this action in reports, papers, and articles besides the NOx tax enforced between Norwegian ports. Originally, after the MARPOL Annex VI regulation, a NOx tax was supposed to be levied for new ships sailing in the ECA from January 1st 2016. However, there is uncertainty of its entry as IMO considers postponing it until 2021 after pressure from some of the neighboring states. Should this possibility materialize, the result will be a delay in its implementation if not the next summit in the spring of 2014 will state otherwise (GLE, 2013; Shippingwatch.com, 16.05.2013). Therefore, because of this ambiguity and since the Norwegian NOx tax only is common within its own national ports it forces me to ignore the tax variable of Nitrogen oxide in the following calculation. This variable will in the numerical computation thus be equal to zero. The potential investment cost of SCR will of this reason neither be included in the following cost-benefit calculation.

This calculation will depict the various abatement technologies for new-builds only. One disadvantage of this choice is the infeasibility to depict the possible action of retrofitting an existing ship to a scrubber system, which in fact is a likely option for most ship owners.

The expected premiums on the investment of LNG and scrubber system are approximations chosen after observations in reports (DMA, 2012) and after discussing the subject with interviewees (Wärtsila, 2013). The premium is chosen to reflect the added cost for a typical container vessel operating with the relating abatement technology. Theses premiums cannot be perceived as universal numbers suited for every LNG new-build because it depends on individual variables.

The vessel speed, engine load, days at sea, and engine capacity is assumed to be constant. Fuel prices, discount rate, and investment cost of both equipment and conventional vessels will simply be estimates.

8.4.2.2.NPV and cost-benefit analysis

8.4.2.2.1 General assumptions

Time of investment

By delaying the investment of abatement technologies, the ship owners will save money by continue operating with the existing vessels and postponing any expensive investments in new abatement technologies. For that reason, I make the assumption that these investments will surface 1st of January 2015, and that the associated calculation will start from that date. The capital expenditure will for that reason not be discounted in the NPV analysis below, and the annual costs will be discounted from the year of 2015.

Lifetime

While container vessels in theory are operationally viable to around 25years (Tschudi Lines, 2013), the assumed economic lifetime is much shorter. As any discount factor used in the profitability calculus will mirror the economic lifetime of a vessel, with reference to the average time of owning a ship, a factor of 10 years is the number most often used (Longva et al. 2008). The discounted number used in this dissertation will thus also be 10.

Discount rate (r)

The opportunity cost of capital is commonly referred to as the discount rate. In other words it should illustrate the size of the potential growth should the money be invested elsewhere. In that context it reflects a company's risk profile for economic development. The European Central Bank (ECB) provided the bond yield for the Euro area to equal 3.1% at current time (ECB, August 2013). As this rate only applies to state bonds with high security on investment, a ship owner will require a larger rate of return. With an additional risk premium to cover the uncertainties of the investment, this dissertation will use r = 7% as discount rate.

Days at sea

Generally, larger ships spends more time at sea than smaller vessels as they operate in deep sea trades and have fewer port calls. When considering the ship of focus, a 1000-1500 TEU container ship that mainly operates within the N-E borders, I will assume an activity level of 300 days at sea per year although the actual time at sea is highly individual.

Engine load (l)

The engine load, a measurement reflecting the power used on an engine, will depend on several factors with the main ones being weather conditions, time to arrival, and hours at sea (Wärtsilä, 2013). One could simplify and set engine load at 100%, but that will overestimate the fuel cost dramatically due to the convex relationship between speed and fuel consumption. After discussing it with interviewees from various shipping companies the normal engine load at sea is around 85% (Tschudi Lines, UF, 2013). However, when contemplating the yearly average engine load with the assumption of 300 operating days at sea, the right engine load equals 70% ($\frac{300}{365}$ *85%).

This latter number is thus the one used in the calculus.

Currency

Due to keep consistency I will use U.S. dollars as currency throughout this paper. When converting Euros to US dollars I will use the rate of 1.3522.

Net present value

As explained in section 3.2.1, the NPV analysis will present the value of cash inflows minus the present value of cash outflows during a specified period. I have selected one particular vessel and made use of the associated characteristics accordingly, which acts as a foundation for this quantitative analysis. In this regard I chose the vessel Aalderdijk, which can be viewed more thoroughly in appendix H. As this analysis considers cash outflows only, the strategy with the lowest costs in present value will be the favored strategy. This approach is chosen to reflect the fact that there are only costs accompanied with these technologies, and no revenues. This part will thus portray an NPV analysis of the total cost where the calculation will distinguish between capital expenditures, referring to the investment cost that already is a present value, and the annual shipping cost which will accumulate over time:

$$\mathbf{NPV} = \mathbf{C_{CAPEX}} + \sum_{r=0}^{n} \frac{\mathbf{C_{Annual}}}{(\mathbf{1+r})^{\mathbf{t}}} \tag{1}$$

Where:
n = Expected lifetime in years
r = Discount rate

Capital expenditures (CAPEX)

Capital expenditure will throughout this case study reflect the expenditure of acquiring a physical asset, like a container ship, that will create future capital benefits. As I will discuss the utilization of three different combustion technologies in MGO, HFO combined with scrubber technology, and LNG engine, there will exist three different investment costs accordingly. Because of this, I will use the investment cost of purchasing one vessel with incumbent technology as a base, and use different mark-ups to replicate the cost of each individual investment. These premiums will be in values of percentages. Through my interviews, and discussions with Fearnley Securities (2013) I came to the conclusion that the typical container vessel with incumbent technology will have an initial capital outlay of around 20 million U.S. dollars. As MGO can run on a conventionally used engine found in existing ships, this solution does not need any modifications (W&W, 2013) and will accordingly have zero investment premium. In contrast, scrubber technology and LNG-engines require added adjustments for new-builds which require this thesis to use the associated CAPEX premium of 5%, and 20% respectively. These estimations are chosen after conversations with Wärtsilä (2013) and after regarding the investment premiums used in reputable reports, e.g. Gaszprom (2011). However, when regarding LNG it is important to take into account that this investment in particular is difficult to forecast accurately due to the lack of experience in producing such ships. These numbers are therefore just approximations and have to be considered as such. As mentioned earlier, these capital costs are assumed to be delayed until January 2015, and will because of this already be a present value. These costs will therefore not be included in the discounted analysis.

$$C_{CAPEX} = P_c * (1 + M_p) + \text{Extra costs} \tag{2}$$

Where:

P_c = Investment cost of a standard container ship with incumbent technology

M_p = Premium due to added technological complexity (scrubber system, SCR, and LNG system)

Annual shipping cost

The yearly shipping cost will include the costs related to the operational activity in addition to the utilization of the abatement strategy. These costs will be described below and consists of operational expenditures, fuel costs, emission taxation, the potential loss of cargo space, and interest from the investment. For the latter factor I assume the capital value was borrowed at a yearly cost of 6%.

$$C_{Annual} = C_{Opex} + C_{Fuel} + T_{Em} + L_{Cargo} + C_{Interest} \tag{3}$$

Operational expenditures (OPEX)

These costs are so-called voyage costs which consist of maintenance cost, manning costs, fee for bunkering, and port fees. These will, due to simplicity and small practical difference, be put as equivalents among the various strategies. The aspect of simplicity will also apply to any potential requirements of additional training for the crew members on board when referring to the LNG system. Although it is a discussed subject, the cost of crew training for LNG handling will in this thesis be neglected due to its small costs, and because it often is included in the package bought from any technological company like Wärtsilä. Maintenance costs may however somewhat diverge from alternative to alternative. In this respect, HFO is the resource that has the most need for maintenance. This dissertation will because of this add 2 Euro/Mwh in maintenance cost to this strategy, and 0.25 Euro/Mwh for MGO. In contrast to HFO and MGO, LNG is a way cleaner fuel oil and does not need any substantial maintenance like the others. This latter strategy will thus not have any maintenance cost relating to the energy used on a ship. For that reason, it should be noted that LNG engines have longer life expectancy than conventional engines because of this cleanness. The reason is the lack of sulfur and other particles that are perceived to cause corrosive effects (Wärtsilä, 2013). The costs related to operational activity can be split into two parts. One part covers the costs of the engine operating; a function of running hours per year (h), installed engine power (p), and engine load (l); where the second part covers operational unit costs and can be defined as operational costs per kWh.

$$C_{OPEX} = p * h * l * P_{OP.COST} \tag{4}$$

Where:

P = Installed efficiency (kW)

h = Operating hours per year

l = Average engine load in percent

$P_{OP.COST}$ = Operational unit costs ($/kWh)

After looking at weekly cost projections of my interviewee (NCL, 2013), this dissertation will use an average weekly operational cost of $100’000 for all strategies. Based on the displayed figure I perceive this to be the average for container ships of similar this size. This number will include manning costs, harbor costs, and the like. The potential maintenance cost of using MGO or HFO will come in addition to this factor.

Fuel costs

Fuel cost is by far the biggest contributor to costs for a ship owner, and can represent between 50% and 60% of the total operating costs of any shipping activities (World Shipping Council). Additionally, it is the cost factor that varies the most from one abatement strategy to the next, and will because of this be the main variable of focus in this calculation. This will base the daily fuel consumption on the vessel of focus and retrieve the total fuel cost based on engine load and the cost per metric tonne.

$$\boldsymbol{C_{Fuel} = Kw_{Total} * F_{g/kWh} * P_{Fuel}} \qquad (5)$$

Where:

Kw_{total} = Total energy consumption for individual fuel system

$\boldsymbol{F_{g/kWh}}$ = Fuel usage per energy consumption

P_{Fuel} = Cost of fuel ($/MT)

However, since the propulsion energies have different energy content, the fuel consumption will be rather dissimilar from strategy to strategy. Natural gas has for instance the energy content of 49.62 MJ/kg, while MGO has 42.7 MJ/kg and HFO 40.6 MJ/kg (Wärtsila, 2013). The amount of fuel to get the same sum of energy will thus be higher for HFO and MGO than for LNG. This report will after conversations with Wärtsilä (2013) utilize the estimated fuel consumption of 170 g/kwh for MGO, 176 g/kwh for HFO, and 146 g/kwh for LNG.).

HFO in particular, has several characteristics that need particular attention. In this context it has certain traits that require added energy. HFO is for instance a tenacious and viscous liquid that requires heat to achieve the right viscosity to run in fuel pipes. As a result it needs pumps to drive the fuel from tank to engine. On top of this, the HFO strategy has a scrubber mechanism that cleans its waste product. And as all these processes require energy the consequence will be a fuel consumption that is higher for HFO than the other propulsion energies. This report will also assume that the required energy is provided by the main engine only, which naturally it will affect the total fuel consumption. Based on the engine capacity of the vessel in focus and the average engine load of 70%, this analysis will therefore use the daily fuel consumption of 43.6 ton of HFO, 41.5 ton of MGO, and 35.6 ton of LNG.

Emission tax expenditures (TaxEx)

Tax expenditures of emission could potentially surface should a vessel emit illegal substances during operations in the ECA, either at berth or at sea. If caught by authorities, Danish Ministry of Environment (DME) (2013) state that a vessel will be prevented to operate further until the fuel has been changed. Additionally, there will be levied a tax based on the emission of contaminated discharges. However, there are currently no public emission taxes present in either the Baltic Sea or the English Channel, and in contrast only a NOx tax in the North Sea (DME, 2013). Since the NOx tax only affects vessels sailing in between Norwegian ports (regjeringen.no, toll.no), it will not affect the general North European ship owner, and thus not the typical feeder vessel operating in the selected waters. Because of this I will neglect this factor in my calculus. DME (2013) endorses this action by stating that the European Union neither has a direct plan of taxing emissions in the nearest future, although it might come in a later period. Their way of controlling for compliance with environmental regulations will thus only be by controlling ship documents, fuel samples in ports, and by prohibiting these vessels to leave the port until new fuel has replaced the illegal bunker oil. Fees can also be given, although none has been given up to this date, and there is not a formal structure for the amount that should be given (DME, 2013). Any future emission taxes will however be in the favor of LNG as it is the abatement technology that has the lowest emission discharge to the environment. This is portrayed in table 4 at page 71.

$$T_{EM} = p * h * l * P_{Emissions} * E \qquad (6)$$

Where:

$P_{Emissions}$ = Tax per tonne contaminated discharge

E =Tonne emitted of illegal discharge per kWh (kg/kWh)

P * h * l = Operating effect of the engine

Loss in cargo space

As LNG tanks are larger and more complex than HFO tanks they require larger space to provide fuel that covers the same operational distance as the conventionally used HFO tanks. In order to ensure the liquid form of the natural gas, adequate pressure and permanent cooling is necessary which demands three times as big tanks which consequently take up existing cargo space (Wärtsila, 2013). The loss of container space will thus be 2 times the size of the existing HFO tanks which will equal a certain amount of TEUs per voyage. To calculate the total cost of this loss in cargo space, I will multiply the loss of containers by the price of transporting 1 TEU. The price of transporting 1 TEU from Oslo to Rotterdam is roughly around 800 Euro according to industrial players (Tschudi Lines, NCL, 2013). In dollars this will amount to 1082 USD. The calculated cost will thus be the following:

$$\mathbf{L_{cargo}} = \frac{(2*V_{tank})}{1\,TEU\,m^3} * T_{cost} * \mathbf{O} \qquad (7)$$

Where:

V_{Tank} = HFO tank volume size

T_{Cost} = Loss in transport cost per operation (cost of the # containers sacrificed)

O = Number of yearly operations

Interest

The normally used interest rate in cost-benefit calculations are 6% (Wärtsilä, 2013). As a result, this calculation will also use this rate as well as considering the potential premium.

$$I_{interest} = [C_{CAPEX} * (1+M_P)] * r \tag{8}$$

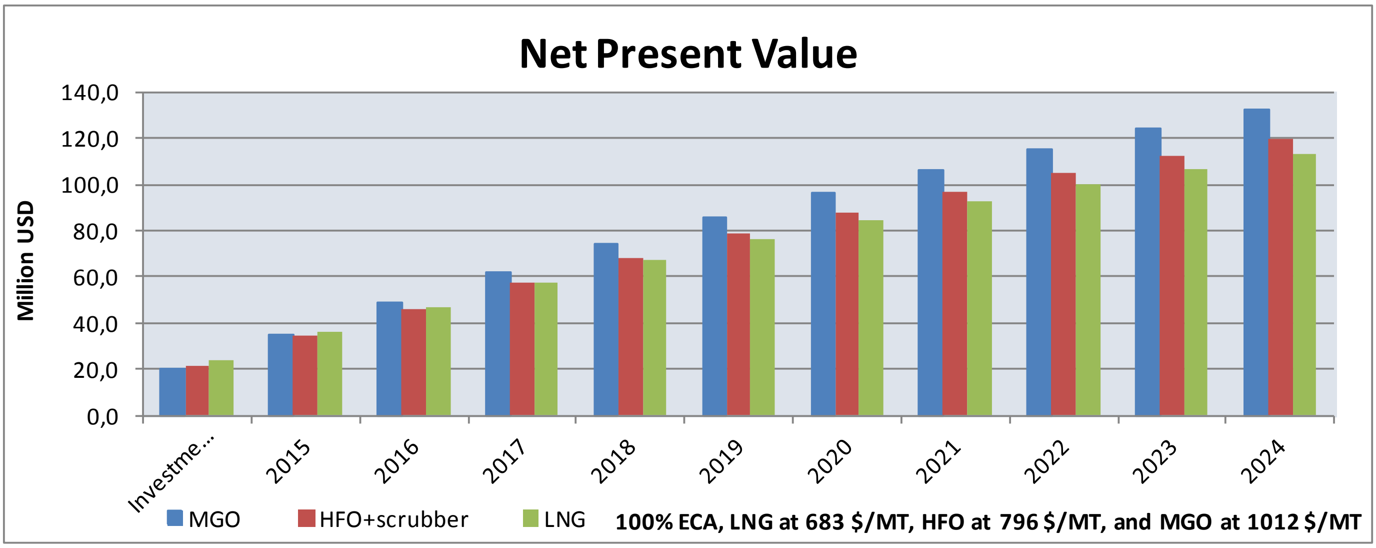
8.5 Results

This part will contain the results of the economic analysis presented above. The outcome is presented here to provide a better understanding of the economic effect each individual abatement technology have on the economic base line of a shipping company. It is important to have in mind that this section analyzes the numerical aspect only, and that a more elaborated discussion of the feasibility of LNG will follow in chapter 9.

8.5.1 NPV analysis

As already mentioned, this quantitative analysis will emphasize on the total life cycle costs of each strategy: the cost of the LNG strategy, the HFO strategy, and the MGO strategy. When compared, the favorable strategy will be the one that yields the least cost. However, all costs in the calculation are not negative. Cost advantages will offset some of the expenses where these will have different appearances depending on the abatement strategy in focus.

Figure 15: Net Present Value analysis of the different abatement strategies over a ten year period



As can be seen from figure 15, LNG as marine fuel is the most cost-effective alternative under the current prices. Over the assumed economic life-time of a container vessel, the payback time of the LNG strategy will be somewhat rapid and stabilize at that level throughout the expected duration. This economic advantage is mainly due to the lower fuel price of LNG, where this analysis have utilized an NBP gas price of 483 $/MT and an added distribution cost of 200 $/MT[7]. The lower fuel cost has additionally been positively affected by the high energy content in gas which results in a lower daily fuel consumption in contrast to HFO and MGO. My analysis has come to the conclusion that LNG would remain its profitability compared to HFO until the oil price falls below 99.5 USD/bbl. Reversely, the LNG fuel price will have to increase to 764 $/MT should it be equally profitable as the HFO and scrubber strategy, and 935 $/MT should it be equal to the MGO strategy. In line with this relation, the price per container (TEU) would as well be increased to $1588 to be equal to HFO and scrubber, and $2649 before it will be economically equal to the MGO strategy.

8.5.2 Payback analysis

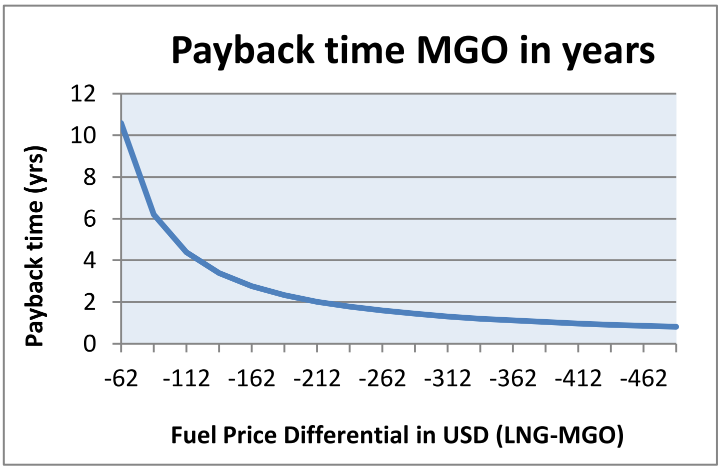
As mentioned in section 3.2.2 the payback method is a comprehensive measure to assess a financial investment. By calculating the time of years it takes to generate the adequate return to repay an investment one can illustrate the attractiveness of a financial asset. In order to create this payback analysis I used the MGO alternative as a “baseline” to which the other abatement strategies were compared. This means that, since the strategy of marine gas oil does not require any additional investment to function, it has no investment premium. The other alternatives, on the other hand, have an investment premium of 5% ($1 mill) and 20% ($4 mill) for HFO and LNG, respectively. And as these added costs will have to be re-paid in order to become more profitable than MGO, it will require time and certain factors that ought to be less expensive to provide cost savings.

$$Payback\ Period = \frac{Investment\ premium}{Annual\ Cost\ Savings_{LNG\ vs.\ HFO/MGO}}$$

In this regard, since the fuel cost is the factor that is the most dissimilar among the abatement strategies and because it is very influential in the total costs, it is of main focus in this analysis. A consequence is that the economic viability of LNG also will be largely depended on the added distribution cost of LNG fuel. This study will also assume that these costs stay stable throughout period.

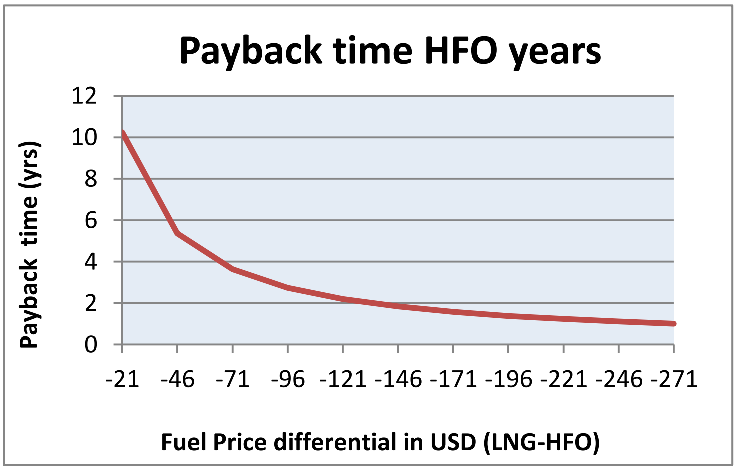
[7] NBP price is collected from the month of May 2013. In section 8.2 I determined to value the distribution and liquefaction cost to 200 $/MT according to the approximation made in the reputable GL-Man study of 2012.

Figure 16: Payback time for LNG to MGO



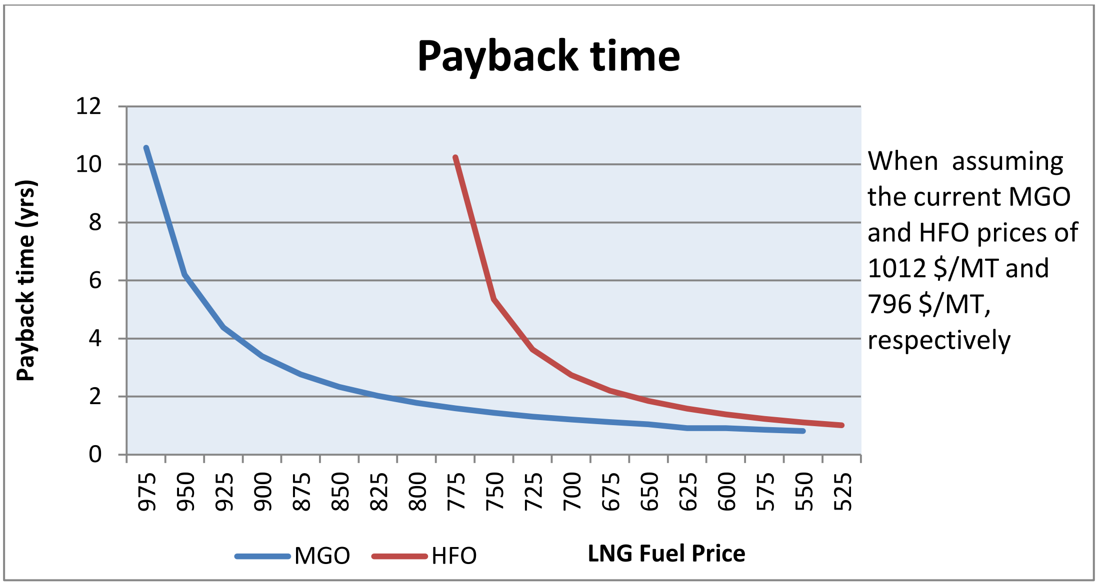
The fuel price differential is currently 329 $/MT.

Figure 17: Payback time for LNG to HFO



The fuel price differential is currently 113 $/MT (May prices)

Figure 18: Payback time related to LNG fuel price



At current prices (May 2013), the payback time to repay the added investment of LNG in comparison to MGO will be 1.238 years. To do the same compared to HFO it will require the time of 2.351 years.

9. Qualitative analysis

High-quality investment decisions demand a thorough and comprehensive evaluation of any asset of focus. In this sense, a quantitative analysis will not suffice to provide an adequate elaboration of the investment alternative. This section will therefore endeavor to appraise LNG more extensively through a macro economic stand point and from an innovational point of view.

9.1 PESTEL analysis

PESTEL is a tool for external analysis that uncovers different variables of an industry. It has received its name after the abbreviation of the different factors that affect a company's function and behavior. It stands for political, economical, social, technological, environmental, and legal factors. All the different factors are important when molding an organization towards an optimal business position.

9.1.1. Legal factors

We start off with the legal factor given that it is the main reason for the emergence of LNG as marine fuel. As ship emissions are subject to increasingly tighter regulations, the seaborne transport industry has to change their fuel oil and move towards greener technology. Through the MARPOL Annex VI regulation, which entered into force in 2005, ship emissions of air pollution will be reduced incrementally in the future. The limit is expected to reduce the sulphur content in fuel oils from the current 3.5% to 0.5% in 2020 globally, and 1% to 0.1% in 2015 in the ECAs (IMO). As mentioned in section 5.3, there are several ECAs existing today, where the figure below can display this further.

Figure 19: An illustration of the existing and potential future ECAs in the world

Source: GLE (2013) – Gas LNG Europe Overcoming barriers in the Small Scale LNG development

The Annex VI was also supposed to regulate the emissions of NOx from January 1st of 2016, but after pressure from east-Europe, and mainly Russia and Polen, it may be postponed to 2021. The action has been condemned by several environmental organizations that pressure EU to adapt its own NOx limits for vessels in the area (WW, 2013). It is stated that this IMO decision will be voted again in the next Marine Environment Protection committee anticipated to be held in March 2014 (dieselnet, 16.05.2013).

The IMO has long wanted to decrease the CO_2 emissions from ships. Eventually it materialized as an added chapter in the MARPOL Annex VI with the names Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Plan (SEEMP). They entered into force the 1st of January 2013, and apply to new-builds and to all ships after 2013, respectively. The main point is to force naval architects and owners to develop vessel designs that are progressively more fuel efficient which emits less green house gas (GHG) (IMO).

As LNG is the abatement technology that reduces the emissions the most, it is the best resource on the market to comply with any future amendments to MARPOL Annex VI. It has thus an advantage over other competing fuel oils as the alternatives in MGO and scrubber technology need additional components to comply with any future regulations, should they materialize. As a consequence, these latter abatement strategies will potentially require extra costs and investments that LNG, in contrast, does not have to consider. IMO's actions have demonstrated a rather clear demand for the future maritime business. Through their behavior they have guided the direction of where the industry ought to be headed: the greater focus on the environment the better. However, the organization's turnaround to succumb to pressure of mainly Russia, with the possible delay of the NOx tax, is a significant downturn for LNG and a step down from the pressure to modify the emissions of the industry. As the possible postponement may result in the lack of immediate requirement for a cleaner fuel oil, LNG's foray in the shipping industry will possibly be somewhat slowed down.

9.1.2. Social factors

Despite being vital to society, awareness of LNG is usually low, where the gas itself often relates to the flammable substance burned at oil rigs. In reality, natural gas is an important alternative to meet the public needs for heating, cooking, transportation, and electricity. In addition to its high versatility, it has a high energy value which altogether should induce the resource to be well appreciated among the public. However, as it is merely unknown to the general public, individuals may both perceive gas as a powerful energy source and as a source likely to cause harm in the form of explosions and fire. Because of this lack of knowledge they might simply fear it, and therefore work against plans preparing terminals to be located too close to public communities. One illustration in this regard is the image of LNG terminals as potential "ticking time bombs" ready to explode in the presence of the smallest spark (Alan M. Herbst, 2004). However, when comparing it to other energy fuels like petroleum products, one can see that it has several advantages.

1. It is generally not explosive, not toxic, and not carcinogenic
2. LNG is lighter than air causing spills to dissipate

3. While portions of an LNG vapor cloud may be flammable, an unconfined cloud will not ignite or explode.

When considering its competitive propulsion energies, in MGO and HFO, these latter resources are both extremely flammable and toxic (in liquid state). In addition, any spill of these resources may cause severe environmental impacts. In contrast, natural gas is only flammable when mixed with oxygen in the range of 5-15%. If the fuel concentration is below 5% it cannot burn due to insufficient fuel, and if it is above 15% it will not burn as a result of insufficient O^2. The result is an energy source that has an extremely low probability to harm the society (Alan M. Herbst, 2004). This probability is based on several factors:

- A large amount of LNG must be spilled in a very short time in order to generate a vapor cloud likely to reach populated areas.
- Because of systems control, that limits volumes spilled from pipes, any large LNG spill must come from a tank rupture.
- The force required to cause such a tank rupture will most certainly result in a fire at the tank location. And if there *is* a fire, there will not be a vapor cloud due to the fact that the gas would burn at site.
- Both vessels and terminals are equipped with gas, smoke and fire detection devices should a fire actually occur.

9.1.3. Political factors

The political aspect has factors ranging from environmental concerns to the political instability caused by confined economic times. This section will because of this elaborate further on these two aspects.

Environmental concern

The environmental concerns from politicians have existed for a long time, although they have not been serious enough to force any adjustment of common practice. The later years have however changed this view where the preservation of the environment has gotten larger emphasis on the political agenda.

Increased demand for environmental friendly actions

The Intergovernmental Panel on Climate Change (IPCC) published the 1st part of their report on ‘Climate Change 2013’ the 27th of September this year. In the report they concluded with a 95% certainty that the global climate change is manmade where they subsequently forecasted changes in weather, temperature, and increased sea level should there not be a sudden change of actions. The likely result will be a greater global focus on environmental subjects where the general public, as a consequence, may demand more environmental friendly solutions. Accordingly, the demand for abatement technologies like LNG will rise and provide an improved outlook for the strategy. The increased public awareness will also result in an increased promotion around the shift from crude oil to new types of marine fuel. Should this be a materializing factor, public pressure could guide governments to endorse actions that results in the constructions of new LNG establishments.

Political instability

A question one may pose is if political instability and low economic growth dampens the enforcement of environmentally damaging crimes and concurrently the industry's motivation to move towards greener technologies. As the globe experienced a significant setback of the economy due to the credit crisis in 2008, it hampered the main conditions for economic growth and wealth. The demand for new vessels stopped completely and the motivation to commit extra expenditures for greener technologies did the same (Wärtsila, 2013). Additionally it created political instability with the discussion around euro as currency and as an economic union. In turn, these political difficulties were serious and severe and had a probability to jeopardize the safety precautions of the environment set forth by IMO. However, IMO maintained their objectives and sustained the demand of ship owners to reduce the release of pollutants to the surroundings. In this view, the political instability had no damaging effect on the emission regulations set out by IMO. On the other hand, politicians neglected the focus on supporting the development of LNG infrastructure, which now haunts the growth of the fuel oil. It plays a big part in the future of LNG which can be exemplified through the infamous chicken and egg quandary where infrastructure has to be present in order for demand to surface and vice versa. Any delay in its materialization can therefore result in uncertainties of its future potential and thus act as a central barrier to its adoption.

LNG infrastructure

The unavailability of LNG infrastructure is today perceived as the other main impediment for its endorsement and utilization by ship owners (GLE, 2013). As Europe is not a geographical region with abundance of natural gas, the resource is transported from the production and liquefaction sites elsewhere in the world, and especially from Iran, Russia, and Qatar (Reuters). The European need for infrastructure will thus be import and bunkering terminals. As you can see from figure 6 on page 37, the N-E ECA lacks adequate LNG terminals to supply the potential future need in the Baltic Sea. The consequence is that no container vessel can operate on LNG in the area until this is developed, as they would lack bunkering stations to tank their fuel needs.

To increase the availability of LNG for marine customers, it is essential that a supply system consisting of LNG feeder vessels[8], smaller-scale terminals, bunker vessels, and LNG trucks will be established. An adequately large system is vital to reap economies of scale and to bring down the associated costs from a large terminal to supplying the customers with a reasonable bunker price (DMA, 2012). This is especially important in the early age of LNG to capture demand from HFO and to direct the resource towards a prosperous route. The Danish Maritime Authority (2012) states that a number of small-scale terminals are expected to be established in nations alongside the ECA by 2020. One may however question the tardiness of this procedure, and how its potential delay will affect natural gas as marine fuel. Nevertheless, the Danish organization forecasts the LNG market to grow rapidly in the years of 2015-2020 which consequently will need more supply and bunker terminals (DMA, 2012). Its future outlook will mainly be considered in relation to new arising technologies, its price, and its availability in contrast to MGO and HFO. However, the bottom line is that LNG needs a more fine meshed supply infrastructure and to increase its availability should it manage to triumph its competitive fuel oils. And since infrastructure is so important for the LNG development, any postponement or hindrance in its enlargement will also delay the foray of LNG as marine fuel in the shipping industry. As positive news there are expected that various ports will develop LNG facilities in the future. Examples in this respect are how the port of Gothenburg plan to build an LNG terminal by 2015 (Project GO_4LNG), the port of Hamburg by 2014 (port strategy), and Klaipeda in Lithuania by the end of 2014 (LNG world news). A combined overview of the planned, proposed, and existing LNG terminals can be seen in figure 6 at page 37.

Another element that might block the rapid introduction and embrace of LNG is the possible delay of the Tier III regulations from 2016 to 2021 (dieselnet, 16.05.2013). It simply blocks the pressure for the transformation to greener technology and creates an indirect statement of it being 'acceptable' to continue the current trajectory of emitting harmful substances to the surroundings. This possible delay is also a portrait of the various differences that can be found in the countries surrounding the N-E ECA. Financial stability, political systems and political ideologies may all be dissimilar in such a large area which consequently may turn to different attitudes towards various subjects. As a result, political disputes and conflicts may potentially be created which ultimately can cause a negative influence on LNG infrastructure and as a consequence have a negative effect on the possible upsurge of the fuel oil.

[8] LNG feeder vessel is a ship transporting LNG from import terminals to smaller-scale terminals for the continuous distribution of LNG to marine customers.

9.1.4. Technological factors

Operating with LNG instead of conventional fuel oil implies several differences in regard of the technological aspect of a ship. In particular this refers to the propulsion system, ship design and fuel storage (aboard and on land), bunkering process, and safety. Although an LNG driven vessel requires different ship design and propulsion system, gas engine technology is widely available. It is important to add that LNG driven vessels neither are new to the industry. LNG carriers have for years used the "boil of gas" from gas tanks to create propulsion energy. And at current date there has additionally been launched, tested, and approved several engine concepts that runs primarily on gas. One of these concepts is the Dual Fuel Diesel Electric (DFDE) engine which mainly operates on LNG fluid, with the added possibility to use another fuel oil like light fuel oil (LFO) or HFO (GSF 2012, technical report). This provides the independence of one particular fuel oil in addition to the opportunity to use diesel oil whenever sailing outside an ECA and where the LNG infrastructure may be not as extensive.

When considering the optimal ship design to incorporate the larger LNG tanks, Wärtsilä (2013) happily informs that this is a process steadily improving, even though it currently can be perceived as a small barrier for LNG embracement. However, the tanks' excessive size is possibly one of the most difficult problems to bypass in the technology section, and even though Wärtsilä may state their optimism it is important take into account this obstacle. The fact is that LNG tanks are around three times as big as diesel tanks, which results in the challenge to find enough space onboard without losing too much valuable cargo space (W&W, 2013). When appraising LNG regarding the aspect of profitability, this factor is thus especially important to consider.

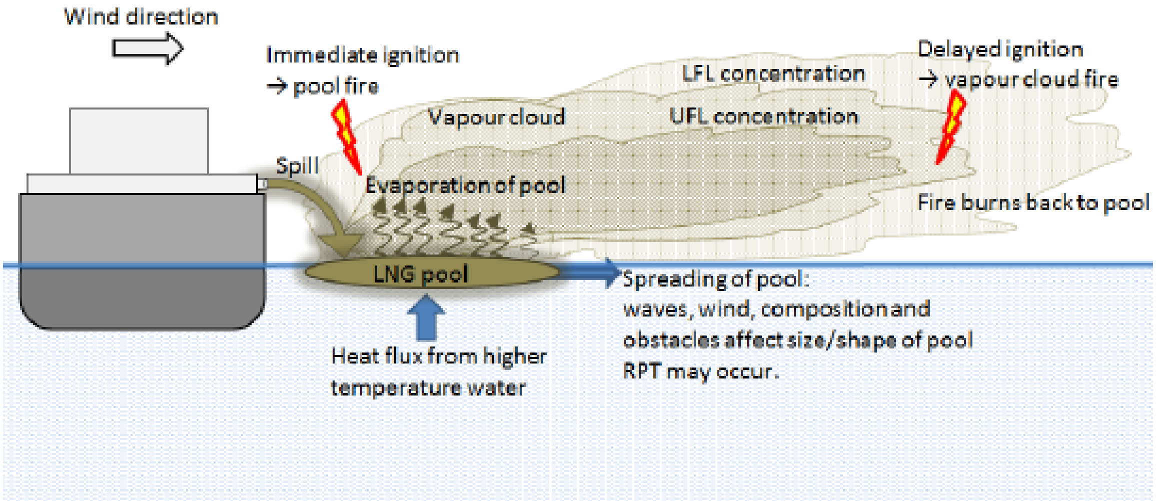
Bunkering systems has proven to work through three different transfers, as mentioned in section 7.3, and reflects accordingly no technological hurdle. Lastly, there is the subject of safety towards LNG technology and how well protected the public are to potential accidents. In this context it is important to specify the potential risks that may follow the utilization of LNG as marine fuel. The following scenarios are the ones governing the most concern to the surroundings. (1) The cryogenic tanks may be damaged which can cause metal embrittlement, cracks, and structural failure. (2) Cryogenic injuries may cause frost burns, and (3) thermal radiation may occur from various fire scenarios:

- Delayed or immediate ignition of vapor clouds (flash fire)
- Slow fire front
- Delayed or immediate ignition of vapor-air mixture (fire ball)
- Rapid burn

- LNG pool fires
- Flame jets from leaks in pipes, hoses, tanks or pressure vessels
- Vapor cloud explosion

The figure below illustrates these hazards where the potential formation of an LNG pool and the accompanying vapor cloud may cause complications.

Figure 19: Possible outcome of LNG spill over water.



Source: SSPA

As already discussed in the section of social factors, the likelihood of an accidental event is extremely small (Alan M. Herbst, 2004). In any case, the risk is smaller than for its competitive fuel oils, which makes this aspect insignificant and actually in favor of the LNG strategy. In conclusion, there are no significant technological factors, besides the loss of cargo space which may be a preventing factor for the growth of LNG in container ships.

9.1.5. Environmental factors

The mindset of profitability has guided today's business owners to somewhat neglect the environmental aspect and rather focus on the features that contribute to increased economic earnings. However, as the world today perceive the global environment to have reached a saturation point in regard of emissions, actions of disregard is no longer tolerable. Great forces are therefore currently involved in changing the harmful trajectory of the world, where summits and stricter regulations happen repeatedly. The focus has now turned to air emissions and global warming, where stern directives will guide the future behavior. When considering the shipping industry, regulations have already been set forth in various ECAs around the world, which force ship owners to take a leap into greener technology. Such heavy emphasis on preserving the environment is only positive for LNG as it is the greenest alternative on the market, and that it has characteristics that go beyond the regulations of the MARPOL Annex VI (table 4 at page 74). There is, however, still a debate regarding the benefits of the reduction in CO_2 as LNG's main substance is methane which is a highly potent GHG. Methane's amount of GHG is in fact estimated to be over 20 times that of CO_2 for the same quantity, an amount that more than offsets the gain from reduced CO_2 emissions (EPA). However, Rolls-Royce (2012) state that new engines cut methane slips to very low levels and cause a GHG reduction potential in the range of 20-30% with reference to HFO. In conclusion, LNG is the optimal abatement strategy for a greener environment, and is the most favorable technology for vessel owners should new regulations surface in the future.

Clear safety regulations

As already mentioned, LNG has an excellent safety record worldwide which can be attributed to the strong emphasis on detailed industry standards, strong regulations, and industry commitment to risk management (CEE). For all LNG terminals, the focus on protection and safety is large in order to minimize the likelihood of LNG release and to mitigate any consequences should a release actually occur (CEE). The industry proves this commitment by labeling 'safety' as the most essential requirement for its future development (GIIGNL). This seems to be a logic attention as the industry has expressed the LNG concept of being the cleanest and greenest technology currently on the market.

However, safety should not be too dominating so that it negatively affects the vessel's operability. These rules ought to be somewhat flexible, where they for instance could be designed to allow bunkering while simultaneously loading/unloading cargo or embarking/disembarking passengers. Nevertheless, bunkering procedures should be completed as safely as possible and be done through standard routines to ensure compliance of adequate regulations. However, despite different initiatives there is not yet any standard international legislation for the bunkering of LNG as marine fuel (GLE, 2013). Because of this there is also lack of one harmonized bunkering procedure as different ports require different procedures and technical requirements (European Commission, 2012). One important point is therefore that these procedures should be standardized internationally to simplify the compliance from vessel owners and to limit the adherence of multiple guidelines all at once. Although such a document currently is under review by the Oil & Gas producers, it is only in its infancy and has not been developed into an ISO International Standard (GLE, 2013).

9.1.6. Economic factors

The economic aspect is often the first subject any market player would emphasize when assessing a novelty. Below are a number of different variables that together form the economic aspect of LNG as marine fuel.

Global economic downturn

Two consequences of the global economic downturn in 2008 are ship owners' low demand for new vessels, and the lack of willpower to implement environmental enhancing technologies for the sake of improving ship emissions. A constrained economy and a competitive industry may be two factors to blame for why green technology has not forayed into the shipping industry sooner. New-builds were neglected due to the high investment cost, and because abatement technologies have a cost that simply are perceived to be too high with no economic benefits. The credit crisis forced companies worldwide to save money wherever possible to reverse the financial instability and to see positive numbers once again. Less amount of money was therefore used on things that did not clearly affect the economic base line, with the result of smaller amount of capital directed towards ambiguous strategies to increase revenues. Becoming the frontrunner of a greener transport industry to commercialize an ecologic profile to their customers was thus no longer an attractive strategy among industry players (Tschudi Lines, 2013). Consequently, confined economic times can be viewed as an impediment to the construction, retrofit, utilization, and the development of new and greener alternatives to the current polluting HFO. Both Unifeeder (2013) and Tschudi Lines (2013) exemplify this by portraying IMO's future regulations as a black cloud in the horizon, where the cost accompanied with the required ship adjustments simply threatens their survival. The possibility to modify *existing* ships to comply with future regulations is also an option perceived to be too expensive by the industry.

Additionally one has to reflect over the likely predominance of supply over demand for new builds for the foreseeable future. A result of the fact that ship owners understood the seriousness of IMO's regulation rather late they have postponed the final decision of investing in abatement systems (Tschudi Lines, 2013). And even though more LNG driven ships are expected to be built, there will probably not be a high demand for this marine fuel in the immediate future (Tschudi Lines, 2013). Since both important investment decisions and the construction of the vessel itself take time, it will naturally cause a delay for the demand of gas as marine fuel. As Wärtsilä (2013) stated, the current demand for new container ships has decreased tremendously due to the confined economic times. Additionally, the aftermath of the credit crisis has left the transportation margins at very low levels, resulting in difficulties in generating revenues as well as an increased number of available vessels that simply waits at berth. Any demand for new-builds is therefore nearly non-existent at current time (Tschudi Lines, UF, 2013).

LNG price

The price of LNG as marine fuel can both be categorized as a potential barrier *and* as an enabler of its adoption. LNG has however one major obstacle in its deficiency of not having one global price index. As the current LNG price instead is determined locally it is based on dissimilar linkages to competitive fuel oils, with the result of large price differences within the various regions (see figure 8). For Europe today, the natural gas index of NBP show gas prices that are lower than MGO and HFO (Bloomberg). However, the LNG price is not determined by the gas index alone as the closing price will have an added premium caused by liquefaction and distribution costs. The difficulty that emerges is that this added cost is not globally fixed, but instead is sat locally. In any way and as stated before, this report will assume an added premium of 4 $/MMBtu which equals to around 200 $/MT. It is a reference to what other reputable organizations use in their reports (GL & MAN, 2012). Additionally, as there is no global price index today the question regarding LNG's viability may naturally be referred to its price development in the various regions. This importance in price is especially true since the LNG driven vessels normally are more expensive than the ones with incumbent technology in addition to currently lacking sufficient bunkering infrastructure. In any way, LNG has at current time a price that might entice vessel owners for a potential conversion to LNG fuel. As it originates from natural gas it has a natural tendency to follow a gas index. Based on such an index, figure 8 illustrates that LNG would have a highly competitive price compared to MGO and crude oil. At current date the indexed prices of NBP show a price difference between natural gas and HFO that is around 310 $/MT, and around 530 $/MT between natural gas and MGO (Bloomberg, 2013). Consequently, vessel owners can potentially benefit greatly from using LNG and its lower fuel cost, even with a likely added liquefaction cost of 200 $/MT. This development is however ultimately in the hands of the global economy and is thus very ambiguous to discuss further.

At current date the world economy may be projected with a slow but steady positive progress (Aftenposten, 31.10.2013). This is illustrated through the gradual recovery of the U.S. and the European Union. And although China, the global economic superpower, has a somewhat shaky outlook due to a local debt predicament with an expected decrease in future economic growth, the global economy is perceived to be in slow recovery (Aftenposten, 31.10.2013). The conclusion for the shipping industry is therefore that the current demand does not scream for new container vessels and that LNG-powered ships, for that reason, neither seem to be a particular requested item for the time being. The LNG price will because of this doubtfully have a significant increase. Consequently, this will result in a low LNG fuel price that may motivate a possible shift in marine fuel and thus propulsion engine for vessel owners, should infrastructure be adequately developed. Additionally, due to the world abundance of natural gas, where the reservoirs are located in various places around the globe, there will most likely not be any price collusion as we see in the middle-east and OPEC today. The gas industry does simply not have the same opportunity for any similar price agreement, which likely will keep a future LNG price at a low and steady level compared to crude oil.

Subsidy

As safeguarding the environment is high on the current political agenda, various countries are likely to be positive towards endorsing measures that help such a cause. Any subsidy of the development of greener technologies is also mutually beneficial, as it aids both parties. The politicians may rest knowing they assisted the environmental development, while business managers may hope for lower costs and a booming market. An example in this regard is how Norway facilitates the use of electric cars with economic enablers that help raise the demand for electric cars (Energiråd i innlandet, 14.09.2013). When considering the maritime industry, Norway has as well initiated a NOx fund which has received international acclaim. Generally, there is a NOx tax for vessels operating between Norwegian ports, but this fund is however run like a project where the NOx tax is replaced by a yearly disbursement by its participant enterprises. It is a nonprofit fund where all the means received will be used to finance NOx reducing strategies. Once the membership is granted, the participants may apply for financial support for NOx reducing technologies, with the fund being the sponsor (Confederation for Norwegian Enterprise, NHO). The European Commission seeks for similar ways to stimulate the use of eco-friendly marine fuels and considers future subsidies or financial aid to be a possible resort (NHO). For the time being the commission wants to impose the member states to create LNG fueling stations in all 139 coastal and inland ports, the so-called TEN-T core network, which corresponds to around 10% of all EU ports. Their future objective is to build bunkering stations within a distance of maximum 400 km, where the total cost is expected to be covered by the European Unions' member states, by private investments, or/and EU funding (NHO).

Different port dues

According to the Danish Ministry of Environment (2013) some ports have different port dues based on the marine fuel they utilize, which also can be used as a motive to use LNG. The Port of Singapore has for instance adopted such a policy by commencing their Maritime Singapore Green Initiative that encourages companies to implement eco-friendly shipping practices (MPA). They are incentivizing ships by providing a 25% reduction of their initial registration fees and a 20% reduction on their Annual Tonnage Tax. Additionally, should the docking vessels exceed the IMO's Energy Efficiency Design Index (EEDI) they would get additional rebates on their port costs (MPA). However, as these port costs are not excessive one may question their actual effect on the choice of ship fuel

(Ministeriet, 2013). But on the other side, it may illustrate the new trend of the maritime industry – the focus of environmental enhancements.

Emission taxation

Another economic incentive to use greener technology is the savings from emission taxation. As mentioned earlier, any violation of the rules and regulations initiated by IMO will cause grounds of taxation and possible detention from the port it is located (DME, 2013). Additionally, a green strategy will also provide positive perception by clients, and concurrently prohibit any bad publicity relating to harmful emissions to the environment. At present time such a taxation scheme is, however, neither distributed nor informed well enough, which can be proved by the inability of my interviewees to answer adequately when asked about the topic.

Training & education requirements

In order to minimize accidental risk of LNG it is important to regulate standards for LNG bunkering and LNG handling. These standards can be covered by training, education, and the spread of LNG awareness among crew members and land based staff involved in LNG bunkering. There is however an accompanying cost involved with this education, although this process is an ongoing discussion among industry players. As Wärtsilä (2013) state that this issue may, at least initially, be resolved by the willingness of their staff and their peers to train and educate crew members free of charge, Wilhelmsen (2013) argues that the high level of replacements among the staff members make this task impossible in the long run. They assert that the introduction of new personnel is inevitable as the workforce undoubtedly will change during the vessel's operational life-time of around 25 years. The consequence is the unavoidable added cost of training and development which will act as a small impediment for LNG as an abatement strategy.

9.2. Innovation theory analysis

This part will elaborate on LNG as marine fuel and what theoretical implications one has to consider whenever discussing its role in the maritime industry.

9.2.1. Product life cycle (PLC)

In context with the PLC, LNG as marine fuel is clearly at a section of entry and should as a result be labeled as a novelty in its *introduction* stage. It is somewhat unknown to market players and will have to go through a phase of recognition. A new market is created credited to various governments and their environmental regulations, which provide the demand to develop a distribution strategy that suits the stage of introduction. The standard procedure is, according to Magnan et al. (1999), to identify and respond to customer needs as well as to anticipate a suitable adoption related to fuel price, distribution network, and any competitive obstacles that may hinder its foray into an industry.

9.2.2. The expected diffusion of LNG

As Rogers stated, and as I discussed in section 3.1, the development of an innovation was founded on five key-variables through the perceived attributes of innovations. Consequently, if the mass perceive a product's attributes to be of high-quality one could expect its adoption rate to be somewhat speedy. In line with the diffusion curve five elements were discussed: (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability. In the context of *relative advantage*, LNG has several characteristics that induce it to be better than the idea it supersedes. Firstly, it is a greener fuel alternative and has thus emission reducing characteristics. Additionally, according to both the current price index of natural gas and my own calculations presented in section 8.5.1 and 8.5.2, the energy source seems to be economically viable and beneficial for a ship similar to Aalderdijk. However, with LNG there will surface several difficulties ship owners will have to contemplate. The most important ones are probably the high investment premium of around 20% to a conventional vessel, lack of infrastructure, along with the bad state of the global economy. These three variables may cause powerful impediments for the incentives to embrace the technology in the short term, and ought to be combated in the future should LNG have any success. In this respect, section 8.5.2 of this dissertation shows a possible solution to the problem of investment premium. Should the price ratio of LNG to MGO and HFO remain at its current level, the investment premium will only have a payback time of 1.238 an 2.351 years, respectively. From this aspect, assuming the global economy to be on a prosperous route (Aftenposten, 31.10.2013), the next hurdle to overcome is the lack of infrastructure. In this context, the market continuously develop solutions to make infrastructure less costly and less complex, which results in the bunkering aspect to be a plausible hurdle to come across (Connect LNG - LNG convention at HIVE 2013). The large amount of emerging businesses relating to LNG, illustrates this point, where increasing number of establishments have surfaced during the later years (LNG Connect, LNG convention at HIVE 2013).

When discussing its *compatibility* with the existing values and practices, LNG is an undecided alternative. It is a fuel option that is in line with the existing *values* of the industry, as it complies with the environmental objectives of the industry by substantially reducing ship emissions. The future objectives of the world to keep a higher rate of environmental sustainability works in its favor, and will likely increase the popularity of LNG as the years go by. However, it is not compatible with the existing *practices* of the ship owners, which may cause a delay in its implementation. The result of this lack of compatibility is the difficulty of using existing bunker infrastructure, if not simply impossible, and where new bunker stations will have to materialize before LNG can become the new de-facto standard[9]. And because of the low economic margin of the shipping industry, vessel owners view the new regulations commencing in 2015/2016 as economic threats to their survival (UF, Tschudi, NCL, 2013). Any powerful entry of the resource may thus be delayed to a time where new infrastructure is constructed, and when the global economy is stronger with willpower to make investments. Regardless, the industry requires a change from the current behavior. And as LNG is the most optimal long-term strategy, issues of incompatibility may thus be obstacles that are possible to overcome.

LNG has however many of the same qualities as Brent crude oil. Explaining it as propulsion energy similar to diesel, only with characteristics of natural gas, could make it somewhat easy to understand among the general public. The fact that it is an incompatible technology with the need of modifications to use it in existing vessels makes it more *complex* for vessel owners. Retrofitting existing ships are time consuming and costly, which results in the disregard of this alternative with the only real viable option to be new-builds. As LNG is easy to understand but difficult to implement cheaply, its overall complexity for the users in question is thus somewhat unclear. However, when regarding the actual users of LNG, the crew, it will require additional training and education due the new standards and procedures of the technology. It can because of this be labeled as more complex than HFO and MGO.

LNG *can* be experimented with before an implementation of a larger scale. However, it is costly to construct a new-build with LNG as propulsion energy. For that reason, ship owners will often have to make decisions based upon market analyses and experiences from front runners rather than their own know-how and practice. Their *trialability* is therefore often limited to the *observability* of others who actually use the technology. But however, as this possibility to observe is large, a ship owner may anyway get valuable information prior to a potential investment. And, as LNG is very similar to conventionally used bunker fuel, surprises will most often not occur. The experiences collected so far are however limited and originate mainly from Norwegian ferries. The feedback is generally positive with the experience of no big incidents, less soot, no SOx and PM, reduced NOx and CO_2, and less maintenance (DNV LNG experience, 2011). Ship owners contemplating on using LNG as marine fuel can therefore, at least, expect to experience some of the same elements like the ones above.

[9] Means that everyone uses the same system

9.2.3. System competition and network effects

When discussing LNG in line with system competition and network effects it is important to have in mind that LNG is in need of enlargement of its network to become the new standard design as propulsion energy. For this to happen, LNG as marine fuel system has to gain control over a large installed base of users and provide credible grounds for why this new standard is superior to the current system of petroleum related fuel oils. It simply has to provide more attractive offerings to consumers than the incumbent standard (Shapiro and Varian, 1999). In line with this theory, LNG has no distinct differences from other disruptive technologies in various industries. One illustration of this is how the VHS cassette player was replaced by the DVD player due to the latter technology's improved properties, and thus its better offerings. For that reason, LNG will also have to triumph its competitors through improved attributes.. And as I understood by my interviewees, the most vital elements for the shipping industry are currently three main aspects: the elements of *economics*, *LNG availability*, and *environmental quality* (UF, Tschudi Lines, NCL, 2013).

When considering the *economic* part of LNG, the analysis conducted in chapter 8 demonstrates the financial viability of the resource. When regarding the current gas price index of NBP in Europe as well as the added distribution cost of 200 $/MT, the LNG price will be well below its alternative of MGO, and slightly below the fuel price of HFO. When one additionally considers the smaller fuel consumption of LNG, as well as the absence of both environmental taxes and maintenance cost, this dissertation may show that LNG in fact is the cheapest abatement strategy for vessel owners. In contrast to the oil extraction that historically has been taken place in few specified areas, natural gas is additionally an abundant resource present in various parts of the world. A consequence of this is the likely prevention of collusion between market players and in contrast a likely price competition, with the result of price stability and a continued low price.

In the *environmental* aspect, LNG is undisputedly the cleanest marine fuel on the market. Heavy fuel oil, which is the marine fuel that mainly used today, is the one that pollutes the surroundings the most. Particularly the substances of SOx, NOx, CO_2, and PM cause great harm to the local environment. In this respect their effects can be exemplified through acid rain, eutrophication of the sea, and the release of green house gases (EPA). In contrast to MGO, who mainly reduces the emissions of SOx and PM, LNG fuel mitigates all of the emissions of HFO considerably. It contains no sulfur, which has an effect of complete elimination of SOx, and reduces PM to low, almost undetectable levels. NOx emission will be reduced by as much as 80-90% compared to HFO, while CO_2 emission will be diminished by about 20-25%. The latter is explained by its simpler molecule structure than other fuels, which in turn leads to less carbon-containing material and consequently lower CO_2 pollution (MAGALOG project, 2008). These environmental characteristics can be viewed in the table below.

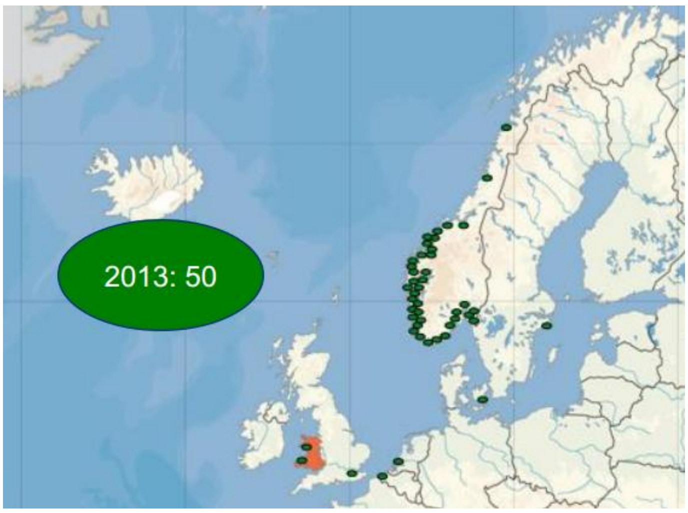
Table 4: Emissions by different marine fuels

Fuel Type	SOx (g/kWh)	NOx (g/kWh)	PM (g/kWh)	CO_2 (g/kWh)
Residual oil 3.5% Sulfur	13	9.0-12.0	1,50	560-630
Marine Diesel oil 0.5% sulfur	2	8.0-11.0	0,25-0.50	580-630
Marine Gas Oil 0.1% sulfur	0.4	8.0-11.0	0.15-0.25	580-630
Liquefied Natural Gas	0	2	~ 0,00	430-480

Source: MAGALOG Project, 2008

LNG *availability* is however modest for the time being. Nevertheless, the planning and development of LNG infrastructure is currently underway, where the number of ports in Europe contemplating to open LNG hubs is steadily increasing. Latest in a series of many is the construction of the second LNG jetty in the port of Zeebrugge and the TEN-T subsidy for an LNG hub establishment in the port of Rotterdam (lng global, ngv global). Furthermore, the Hamburg Port Authority also considers facilitating LNG as propulsion system, where it is accordingly, compiling a feasibility study on the commercial use of the resource (port strategy). Closely related to this trend is the Trans-European Transport Network (TEN-T) which is an organization of the European Union who has the objective to provide financial aid to projects of public interest, to increase efficiency, and to mitigate the global climate change (TEN-T 2012 Annual Call, 2013). In this context there are currently large activities in the region to support and promote both LNG as well as other technologies that reduce the external costs to the environment. Below is the forecast of the LNG infrastructure development from the current year up until 2025-2030.

Figure 20 and 21: Forecasted infrastructure development from year 2013 through 2017.



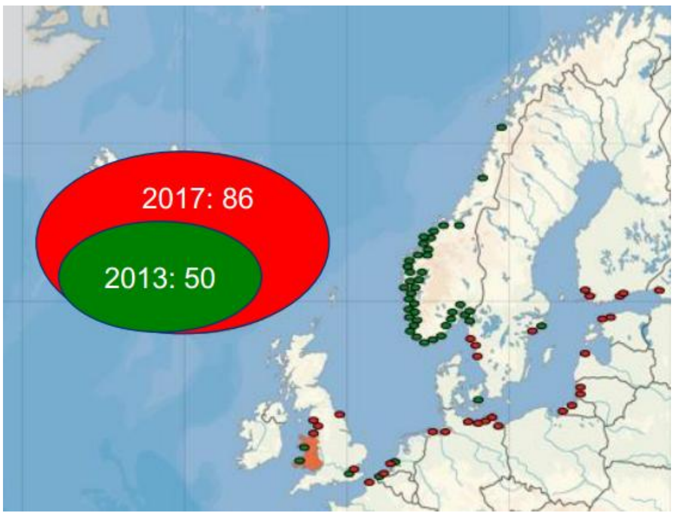
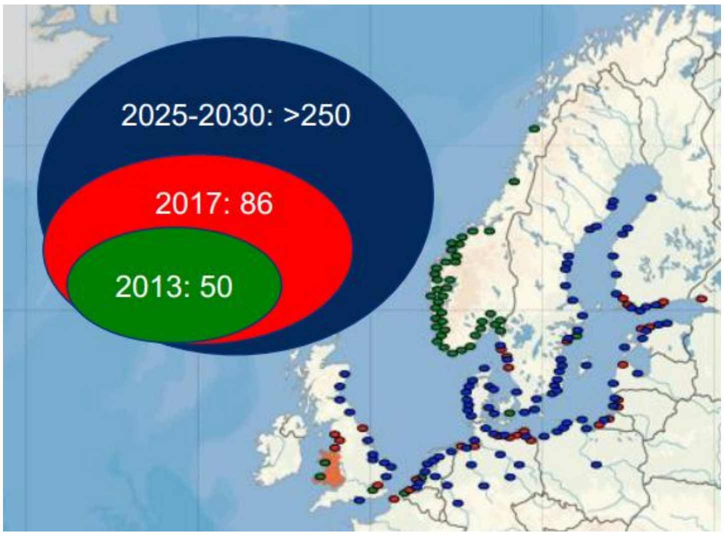


Figure 22: Forecasted infrastructure development from year 2013 through 2030.



Source: Trans-European Transport Network (2011) & EU Commission (2013)

Furthermore, Jin Chyung (1996) advocates the necessity of 6 variables whenever establishing a standard for technologies. As mentioned in section 3.2, he promotes having (1) a large installed base, (2) complementary goods, (3) market acceptance, (4) alliances, (5) suitable margin, and (6) an appropriate platform. For the time being, LNG lacks a large install base due to the fact that it is in its infancy. However, in contrast to the current status, the future outlook does look promising. This can be viewed from the analysis of network effects and the requirement of better offerings than the previous technology. Since LNG can be described as an improved innovation economically and environmentally, with anticipated advancements in infrastructure and availability, LNG may be perceived as having a positive future. On top of that, as industry players, governments, and governmental organizations regard LNG as the most favorable long term abatement strategy, this positive outlook seems especially factual (DMA, 2012; IMO, 2011; SSPA, 2012). In conclusion, I have come across well founded reasons to assume that LNG will achieve the critical *consumer mass* in the future.

As a result of this current immaturity, various *complementary goods* of LNG have not had the time to emerge. Logically due to its youth, this is an understandable fact. Nevertheless, it enlarges the uncertainty for its promising future, as LNG depends on complementary goods to reach the tipping point to become the new "de-facto standard" as propulsion energy (Katz and Shapiro, 1994). When discussing the aspect of *market acceptance*, the technology of LNG is highly welcomed by the industry. In contrast, it is the *situation* that is not met with excitement, where the added costs and regulations related to abatement strategies are important contributors. How this industry eventually develops is nevertheless a question impossible to forecast in detail, and is something that naturally will be affected by the future *business alliances*. Caterpillar is nevertheless a construction company willing to embrace natural gas in machines on land, and has announced an intention to develop engine technology to accompany the future growth for this resource (Caterpillar). FTS International and Cabot Oil & Gas are other businesses adapting to the use natural gas as the primary energy source, where the utilization of power for hydraulic fracturing works as one illustration (FTS, Cabot). However, the global outcome of these possible alliances is still highly uncertain. Nonetheless, due to its versatility, natural gas works as an '*open platform'* as it has the ability to function in various equipments.[10]

Part IV: Concluding remarks

10. Conclusion

LNG as marine fuel has proven to be both environmentally friendly and cost-competitive to the abatement strategies of MGO and scrubber system. These results are obtained under reviewing the current emission regulations and under the various assumptions taken.

From the quantitative analysis it was demonstrated that LNG is the optimal economic option of the three main alternatives at current fuel prices. It was also stated that it remained this profitability over its competitive fuel oils until oil prices moved to below 99.5 USD/bbl or if LNG would move to above 764 $/MT. Compared to MGO it will be profitable until its price exceeds 935 $/MT. It should also be noted that although LNG has the highest investment cost of the tree, it manages to make up for this high expenditure by having characteristics of high energy content and low fuel cost[11]. As concluded from the same analysis it will at current fuel prices have a payback time in years of 1.238 to MGO and 2.351 to HFO with scrubber technology. Additionally, as there is expected that the investment premium of LNG fuel new-builds will fall, this will further strengthen the advantage of the resource (GLE, 2013).

Through the qualitative analysis, this dissertation demonstrates that natural gas has the most environmental friendly features of the three alternatives, with traits that go beyond the Annex VI

[10] The factor 'margin: price vs. cost' is not relevant for the public domain of natural gas, and will therefore not be discussed further

[11] When assuming a distribution cost of 200 $/MT

regulation that enters in 2015 and 2016[12]. Additionally, it is less toxic and harmful than its competitive fuel oils which results in a good match with any potentially concerned consumer. LNG is due to its green characteristics also in line with the political agreement of a more environmental friendly transport industry, but has however one significant barrier. Due to its infancy as marine fuel, there has not been constructed sufficient amount of LNG infrastructure to meet the possible future demand should a potential fuel adjustment from HFO to LNG go smoothly. This immaturity is thus the greatest obstacle to bypass, where the chicken and egg quandary haunts its rapid embrace by ship owners. This, together with the loss of cargo space and confined economic times that prohibits new investments in LNG new-builds, are perceived by industry players as being the largest barrier for LNG today (UF, Tschudi, Wärtsilä, NCL, WW, 2013).

As a result of this predicament, the innovation analysis described in chapter 9.2 holds particularly great value. In this sub-chapter it is demonstrated that LNG is at an introductory stage of its life-cycle. Additionally, it is stated that LNG has relative advantage over its competitors although it is incompatible with neither the existing infrastructure nor the current practices. This is a consequence of its complexity, and above all its diversity, from the incumbent technology. The main question for LNG's viability as disruptive innovation is thus to find the right approach to become the new *de-facto standard* in the industry. In this respect, it finds its potential in being the most economical and environmental friendly marine fuel on the market as well as having a likely future extension in ports that enables LNG fueling (figure 6, 20, 21, 22). Additionally, LNG makes sense for many by being safer and less risky than its competitive fuel oils, as well as being in line with governmental desire for cleaner fuel oils, thereby having a likely support from authorities. In conclusion it seems that LNG, as a disruptive innovation, has the required characteristics to win the standards war and will by time obtain the required critical mass to become the new conventionally used marine fuel. This is especially factual as the existing standard no longer is sufficient to comply with future environmental regulations which as a consequence, will facilitate the arrival of a new standard.

This report also concluded that LNG is not dependent on environmental taxation to be cost-competitive to its alternatives. Although taxes are not currently enforced, this factor can still be seen as a fundamental driver for the technology as taxes are expected to surface in the future (DME, 2013). In line with having supreme environmental performance, LNG goes beyond the regulations of Annex VI and will thus be the best abatement strategy to encounter new and possibly stricter regulations regarding a potential enforcement of CO_2. When discussing the segment of container ships that operates in the ECA only, their regular trading pattern is another advantage for adopting

[12] Not yet determined whether the NOx regulation will enter as planned in 2016 or if it will be postponed to 2021

LNG. A result of these regular visits to certain ports, the marine fuel can be utilized by numerous vessels even before the infrastructure becomes extensive, and may for that reason be heavily consumed before the LNG network actually reaches a level of maturity. When contemplating the analyses presented in this report, LNG is therefore well suited to meet the new environmental requirements set forth by the IMO. All of the analyses suggest that LNG is feasible as propulsion energy, and indicate that there are good prospects for LNG to become an attractive fuel option for any ship segment operating in the N-E ECA.

Proposal of further studies on this topic

As this thesis only considered short-sea shipping, any further studies regarding the viability of deep sea-shipping is welcomed. As deep-sea shipping will require a world-wide extension of an LNG network it may likely take time before an adequate infrastructure will materialize. It would also be interesting to see the feasibility of other shipping segments to run on LNG, besides the sector involving container vessels, and to find any possible discrepancies between them. Another aspect to consider in the future is the likelihood of other abatement strategies than the ones of focus in this study. In this context it would be interesting to view the SCR and HAM technology, DME, bio-fuel, methanol and ethanol related to propulsion energies, as well as other renewable energy sources.

Furthermore, another interesting topic would be to regard the outlook of LNG from the stand point of ports, bunkering firms, and other organizations in the LNG supply chain, and to study if they perceive the future of LNG differently than ship owners.

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