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LNG bunkering: The most efficient solution to emissions standards regulation?

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Abbreviations

BC - Black Carbon

CO₂ - Carbon Dioxide

DFDE - Dual-Fuel Diesel-Electric [Engines]

ECA - Emission Control Area

EEDI - Energy Efficiency Design Index

EGR - Exhaust Gas Recirculation

EU - European Union

GHG - Greenhouse Gas

GT - Gigatonnes

GWP - Global Warming Potential

HFC - Hydrofluorocarbons

HFO - Heavy Fuel Oil

IMO - International Maritime Organization

LNG - Liquefied Natural Gas

MARPOL - Marine Pollution

MEGI - Main Engine Gas Injection [Engines]

MEPC - Marine Environment Protection Committee

MGO - Marine Gas Oil

MOT - Ministry of Transport

MRV - Monitoring, Reporting and Verification

N₂O – Nitrous Oxide

NECA - NO_x Emission Control Areas

NO_x - Nitrogen Oxide

OGV - Ocean Going Vessel

PFC - Perfluorooctane Sulphonate

PM - Particulate Matter

SCR - Selective Catalytic Reduction

SECA - SO_x Emission Control Areas

SOLAS - International Convention for the Safety of Life at Sea (SOLAS)

SO_x - Sulphur Oxide

VOC - Volatile Organic Compound

Abstract

Liquefied Natural Gas (LNG) is a potential solution for meeting new legislation that will significantly limit sulphur emissions from ships, firstly in North America and northern Europe in 2015. The shipping industry is increasingly interested in what role LNG will play in the marine fuels market and when. This dissertation looks at the advantages and challenges to LNG bunkering by examining the current situation and exploring the probability of LNG displacing oil as the preferred fuel in shipping. The uptake of LNG as a fuel will depend on a host of developments and prerequisites such as how bunkering infrastructure and technology proceeds. The development of LNG as a bunker fuel in the immediate future – not in the long term – is also examined.

Περίληψη

Το Υγροποιημένο Φυσικό Αέριο (ΥΦΑ) είναι μία πιθανή λύση προκειμένου να ανταποκριθεί η παγκόσμια ναυτιλία στη νέα νομοθεσία που περιορίζει σημαντικά τις εκπομπές θείου από τα πλοία, αρχικά στην Β. Αμερική και τη Β. Ευρώπη το 2015. Η ναυτιλιακή βιομηχανία δείχνει αυξανόμενο ενδιαφέρον για τον ρόλο που θα παίζει το ΥΦΑ στην αγορά ναυτιλιακού καυσίμου καθώς και για τον χρόνο που αυτό θα πραγματοποιηθεί. Η παρούσα διπλωματική εργασία εξετάζει τα πλεονεκτήματα και τις προκλήσεις σε ότι αφορά τον εφοδιασμό πλοίο με καύσιμο ΥΦΑ, εξετάζει την υφιστάμενη κατάσταση και διερευνά την πιθανότητα το ΥΦΑ να αντικαταστήσει το πετρέλαιο ως προτιμώμενο καύσιμο στη ναυτιλία. Η υιοθέτηση του ΥΦΑ ως καύσιμο εξαρτάται από σειρά εξελίξεων και προαπαιτούμενων, όπως π.χ. τις τεχνολογικές εξελίξεις και τις υποδομές στον τομέα του ανεφοδιασμού. Συνεπώς, εξετάζεται και η βραχυπρόθεσμη τάση ως προς την ανάδειξη του ΥΦΑ σε ναυτιλιακό καύσιμο.

Keywords: LNG bunkering, shipping emissions, marine fuels

INTRODUCTION

The world fleet of sea-going merchant ships of more than 100 gigatonnes (GT) comprises over 104,000 ships. Shipping is responsible for approximately three per cent of total anthropogenic CO₂ emissions, or about 900 million tonnes per year in 2008, according to the International Maritime Organisation (IMO 2012). Most scenarios for shipping towards 2050 predict significant growth in the demand for seaborne trade and a corresponding growth in the world fleet, which is likely to generate more CO₂ emissions.

However, emissions from international shipping cannot be attributed to any particular national economy and collaborative action is necessary to deal with the challenge of reducing emissions. Shipping is an inherently international industry which depends on a global regulatory framework to operate efficiently. International shipping is already, by far, the most carbon efficient mode of commercial transport and continues to improve fuel efficiency and thus reduce CO₂ emissions. But it is fully recognized that CO₂ emissions from the industry as a whole (some 2.2% of global emissions) are comparable to those of a major national economy (ICS, 2014).

Failure to deliver a global and uniform CO₂ reduction regime for international shipping will greatly reduce the ability of the shipping sector as a whole to reduce its emissions. However, the IMO principle of ‘no more favorable treatment’ ensures that standards adopted for shipping are applied equally throughout the world, delivering maximum environmental protection and improvement (ICS, 2014).

As acknowledged by the Kyoto Protocol, emissions from international shipping cannot be attributed to any particular national economy. Multilateral collaborative action is the most appropriate means to address emissions from the maritime transport sector. The international shipping industry therefore believes that the achievement of meaningful reductions in CO₂ emissions will be best achieved if nations agree that the development of detailed measures for the international merchant fleet should be directed by governments at IMO.

January 2015 saw the entry into force of the IMO’s stricter sulphur oxide (SO_x) emissions requirements in Emission Control Areas (ECAs) outlined under the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI.

At the start of 2015, the SO_x limit for vessels operating in Emission Control Areas (ECAs) dropped to 0.1% (unless the vessel is fitted with equipment such as scrubbers to reduce the sulphur in exhaust fumes, or is operating on alternative fuel such as LNG, or has a dispensation conferred by Reg. 14.4.4). The 0.1 per cent sulphur limit that came into force as of 2015 will directly affect in the region of 40% of the world fleet in various ways (OilandGasIQ.com).

Ships have been subject to a 3.5% global limit on the sulphur content of fuel and a 1.0% cap in ECAs, but the 2015 ECA limit necessitates a switch to low sulphur fuel, SO_x scrubber technology or the use of LNG as a fuel.

SO_x is one of the main shipping emissions targeted by the IMO and is related to the sulphur content of the fuel burnt by ships. Limits on the sulphur content of fuel have been introduced on a global level by the IMO whilst ships operating in an Emission Control Area (ECA) are subject to more stringent limits.

Sulphur Emission Control Areas (SECAs) or Emission Control Areas (ECAs) are sea areas in which stricter controls were established to minimize airborne emissions from ships as defined by Annex VI of the 1997 MARPOL Protocol which came into effect in May 2005. Annex VI contains provisions for two sets of emission and fuel quality requirements, a global requirement and more stringent controls in special Emission Control Areas (ECA). These regulations stemmed from concerns about the contribution of the shipping industry to "local and global air pollution and environmental problems."ⁱ

There are four SO_x ECAs in existence: the North Sea, the Baltic Sea, North America and the US Caribbean Sea, and at the start of January 2015 the SO_x cap within these areas dropped to 0.1%, the lowest limit proposed by the IMO. However, the global SO_x cap will remain at 3.5% until 2020 when it is due to drop to 0.5% (this deadline may be pushed back to 2025 depending on the result of an IMO review on the availability of low sulphur fuels). In the nearer term, the NO_x Tier III requirement for newbuilding ships is to take effect in North America in 2016.

At present, ocean-going vessels typically spend 5-6% of their operating time within ECAs, but this figure is growing considerably on a number of shipping routes as a result of new requirements for ship fuel along Canadian and U.S. coastlines (Germanischer Lloyd, 2013 pg.7).

Currently, no single solution can ensure the industry achieves a 60 per cent reduction of CO₂ emissions, especially considering the expected increase in transport demand (DNVGL, 2014b, pg.9). In the longer term, depending on technological developments which at the moment cannot be fully anticipated, the industry believes it should be possible to deliver even more dramatic emissions reductions (ICS 2014). Energy efficiency is certainly part of the solution, but the target cannot be reached unless the industry shifts to low carbon solutions.

This thesis examines the use of LNG as a fuel for ships as a potential solution for meeting new legislation limiting sulphur emissions. The shipping industry is increasingly interested in what role LNG will play in the marine fuels market and when. By 2020 – 2025 sulphur emissions will be subject to worldwide limits.

This thesis examines advantages and challenges to LNG bunkering by exploring the current situation and the probability of LNG displacing oil as the preferred fuel in shipping.

The business case for LNG strongly depends on the designation of NO_x Emissionⁱⁱ Control Areas (NECAs) and Emission Control Areas (SECAs) (WPCI). However, the uptake of LNG as a fuel will depend on a host of developments and prerequisites (such as how bunkering infrastructure and technology proceeds) which this dissertation examines.

Part 1 of this dissertation examines emissions and their various classifications; defines Emissions Control Areas; and explores emissions at shipping ports.

In *Part 2* the set of rules and regulations for controlling emissions from shipping are observed from an exploratory standpoint in order to outline the new requirements for the shipping industry stemming from new regulation and how these will be met relating to sulphur emissions. European Union regulation is specifically looked at as well as that which applies in other areas worldwide.

The *3rd Part* of this thesis touches upon the implications for shipping from reducing emissions via new regulation. The effects are seen in terms of consequences for seaports and especially the need for fresh infrastructure as well economic implications for shipping firms.

Part 4 analyses the basics of LNG and using gas as a fuel with bunkering procedures, LNG safety and regulations governing the use of LNG as a fuel studied in particular. Furthermore, the

advantages and concerns of LNG bunkering are explored in detail.

The worldwide LNG fleet is presented in *Part 5* as part of the assessment of the role of LNG in the marine fuels market in connection with the pace at which change stemming from new emissions control regulation is observed. Economic factors for shipowners, environmental benefits and the factors that determine the uptake of LNG as ship fuel are all examined.

PART 1: SHIPPING EMISSIONS REDUCTION

1.1 EMISSIONS

Under the GHG Protocolⁱⁱⁱ, six gases are categorized as greenhouse gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorooctane sulphonate (PFCs), and sulphur hexafluoride (SF₆).

The combustion of marine fuels results in emissions of many pollutants, and diesel exhaust contains an estimated total of 450 different compound, such as sulphur dioxide (SO_x), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), carbon dioxide (CO₂) emissions and other (Mauderley, 1992).

Carbon dioxide (CO₂) is the GHG most relevant to the shipping industry. Globally, 1,050 million tonnes of CO₂ were emitted by shipping in 2007, doubling 1990 levels. CO₂ emissions represent approximately 3% of the world's total CO₂ emissions.

In addition to GHGs, shipping produces other air emissions, most notably sulphur oxides (SO_x), nitrogenoxides (NO_x) and particulate matter (PM).

According to the European Policy Center (2012), the shipping industry is among the top emitters of Sulphur oxides (SO_x). A total of 2.3 million tonnes of SO₂ (the most common sulphur oxide) was emitted by ships in the seas surrounding Europe in the year 2000. Globally, 15 million tonnes of SO_x were emitted by shipping in 2007, representing a 50% increase from 1997 levels.¹ SO_x emissions from shipping represent between 5% and 8% of the world's total SO_x emissions.

Shipping also accounts for a significant portion of the world's Nitrogen oxides (NO_x) emissions. A total of 3.3 million tonnes of NO_x was emitted by ships in the seas surrounding Europe in the year 2000. Globally, 25 million tonnes of NO_x were emitted by shipping in 2007, representing a 39% increase from 1997 levels. NO_x emissions from shipping represent around 15% of the world's total NO_x emissions.

The comparatively high emissions of sulphur oxides by shipping are the consequence of its being fuelled by heavy oil with a global average sulphur concentration of 2.7%.

Shipping emissions are an important contributor to several major environmental problems, most notable of which is the contribution to climate change. Moreover, non-GHG emissions can cause problems such as acid rain, damage to monuments, a reduction of agricultural yields, water contamination, modification of soil biology and deforestation, as well as negative social impacts (Sustainanalytics 2013).

As the most prominent regulators in the shipping industry are the International Maritime Organization (IMO) and the European Union (EU), this dissertation examines the regulations set by these two bodies in detail further below.

In terms of the contribution of shipping emissions to climate change, latest research has found that emissions from shipping cause both warming and cooling effects on the global climate. CO₂, ozone produced from NO_x emissions, and soot (also known as black carbon, the second most potent global warming pollutant) cause global warming, but other shipping pollutants like sulfate aerosols, NO_x, and organic aerosols can have cooling effects.

While the latest literature suggests, with great uncertainty, that shipping may cause a net cooling impact on a global scale, the warming effects of CO₂ and black carbon emissions from ships are expected to grow with the projected increase in global shipping activities. In particular, warming effects caused by shipping activities in the Arctic region could be especially significant (Laursen, 2015).

Overall trade costs reductions will increase the trade flows between Northeast Asia and Northwestern Europe in average by around 10%, depending on the specific countries involved. This will transform the North Sea Route into one of the busiest global trading routes (Bekkers et al, 2015). With the retreat of Arctic sea ice caused by global warming, more ships are expected to travel through the Arctic, leading to greater black carbon deposition on ice and snow there^{iv}. Given that the warming effect of black carbon is particularly potent near ice and snow, the rise in the number of ships traversing the Arctic would further accelerate snowmelt and sea ice loss, exacerbating Arctic warming and the adverse global warming impacts that are already being experienced by countries around the world, including China (Fung, et al, 2014).

1.2 EMISSIONS CLASSIFICATIONS

1.2.1 NITROGEN OXIDES (NO_x)

Nitrogen Oxides (NO_x) is the generic term for a group of highly reactive gases that contain varying amounts of nitrogen and oxygen. They can be divided into nitric oxide (NO) and nitrogen dioxide (NO₂) (Young, 2006).

Contributing to acidification, formation of ozone, nutrient enrichment and to smog formation, NO_x are deemed between the most harmful gases to the environment. They can be transported over long distances and generate problems to areas not confined to areas where NO_x are emitted.

Since NO_x emissions are formed during the combustion process, the quantity produced is a function of temperature, oxide concentration and fuel used. For this reason, the best way to reduce NO_x generation is to decrease the combustion temperatures.

1.2.2 SULPHUR OXIDES (SO_x)

Sulphur oxides are caused by the oxidation of the sulphur in the fuel into SO₂ and SO₃. They are formed during the combustion process through the reaction: $S+O_2=SO_2$ and are a function of the sulphur content in the fuel (Lyrranen et al., 1999; Flagan and Seinfeld, 1998). Acid rain, health effects and climate change are some of the most important effects.

The SO_x emissions from land sources have decreased over the last years, while the SO_x ship emissions have increased (Olivier and Berdowski, 2001). Endresen et al., 2005, estimate that SO_x emission from international marine transportation in 2002 was about 6.3 Tg. The 95% of this value is generated by the combustion of heavy fuel.

The best way to reduce SO_x is by reducing the sulphur content of the fuel. Unfortunately, low-sulphur fuels are more expensive to purchase.

1.2.3 CARBON DIOXIDE (CO₂)

CO₂ is one of the basic products of combustion. It is proportional to the content of carbon in fossil fuel. It is not toxic; however it is the main responsible of the “greenhouse effect” and global

warming.

Due to human activities, such as combustion of fossil fuels and deforestation, the concentration of atmospheric carbon dioxide has increased by about 35% since the beginning of the age of industrialization.

Transport accounts for 25% of energy-related CO₂ emissions. Shipping accounts for approximately 2% of global anthropogenic emissions of CO₂ but the annual growth rate was close to 2.5% during the past decade (IMO, 2000).

1.3 EMISSIONS CONTROL AREAS

The International Maritime Organization (IMO), a United Nations agency dedicated to the safety and security of shipping as well as the prevention of marine pollution by ships, enacts regulations in relation to the environment through the International Convention for the Prevention of Marine Pollution from Ships (MARPOL)^v.

Annex VI of the Convention specifically deals with the prevention of air pollution from vessels (see Appendix). It covers SO_x and NO_x emissions and indirectly covers emissions of secondary PM through the SO_x limits. SO_x emissions are controlled mainly through a global sulphur cap of 35,000 ppm (3.5%) for bunker fuel, which will be progressively reduced to 5,000 ppm (0.5%) by 2020, subject to a feasibility review to be conducted by 2018.

Additionally, Annex VI allows signatory countries to apply to the IMO for the designation of an ECA with stricter control of ship emissions. For ECAs, the sulphur limit is at present set at 1,000 ppm (0.1%). For those countries that choose to include it, a Tier III NO_x standard can also be included in the ECA. This Tier III NO_x standard reduces NO_x emissions by 75% from the current Tier II standard^{vi}.

To achieve this significant reduction, the use of NO_x emission control technologies is required. The leading examples of these technologies are selective catalytic reduction (SCR), exhaust gas recirculation (EGR), and switching from conventional residual oil to liquefied natural gas (LNG) fuel.

It is important to note that at its March/April 2014 meeting, the Marine Environment Protection Committee of the IMO amended the ECA rules related to the Tier III NO_x standard. Previously, any OGV built in 2016 and later that entered any ECA for NO_x would have to meet the Tier III NO_x standard. The recent amendment allows the previously adopted North American ECA and Caribbean ECA to apply the 2016 date to vessels entering their ECAs. However, for future ECAs, the Tier III standard will be applied only to ships constructed after the date upon which a country's proposal for an ECA designation has been adopted by the IMO, or after a later date as determined by the country applying for the ECA designation.

The International Maritime Organization (IMO), and specifically its Marine Environment Protection Committee (MEPC), elaborated a proposal to reduce sulphur oxide emissions which was adopted in October 2008 and thus authorized by the IMO. In addition to a general long-term tightening of the specifications for the sulphur content of shipping fuels, the limit for sulphur concentrations in shipping fuels was set even lower in so-called "SO_x Emission Control Areas" (SECA).

On 1 January 2015, the Sulphur Emissions Control Area (SECA), along with two zones in North America, tightened restrictions on the sulphur content of fuel used by commercial ships from 1% to 0.1%, in line with the 2013 Sulphur Directive of the European Union.

Sulphur content in ship fuel is hardly regulated in other areas, including the Mediterranean, where it can be as high as 4%. A global limit will be set at 0.5% from 2020; a challenge for the industry, but an essential measure for the environment.

The restriction of sulphur emissions is the main environmental constraint to be imposed on the industry. By 2020, sulphur emissions will be subject to a 0.5% limit worldwide. Developing countries, which depend heavily on marine transport to feed their growing economies, are following the matter closely and trying to have the date pushed back to 2025.

Limits for CO₂ emissions are still being finalized, and ship owners will be included in the next round of global climate negotiations, according to the provisional text for the Paris Climate Conference.

Until now, commitments on emissions reduction for commercial shipping have been made

exclusively by the International Maritime Organization, but the European Council has decided that the EU will take charge of the question from 2018.

The following tables (1&2) summarize sulphur limits applicable in SO_x Emission Control Areas and other sea areas worldwide.

Table 1: Sulphur limits for fuel in SECA

before 1 July 2010	1.50% m/m
between 1 July 2010 and 1 January 2015	1.00% m/m
after 1 January 2015	0.10% m/m

Table 2: General sulphur limits in other sea areas

before 1 January 2012	4.50% m/m
between 1 January 2012 and 1 January 2020	3.50% m/m
after 1 January 2020	0.50% m/m

Most relevant IMO regulations related to the LNG supply chain are:

- The SOLAS convention including requirements for maritime fuels;
- The STCW convention including training requirements for crews;
- The ‘International Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code, referenced within SOLAS Chapter VII, Part C)’ including requirements for the construction and operation of LNG tanker;
- The ‘Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships MSC.285(86)’;
- The ‘International Code of Safety for Ships using Gases or other low Flashpoint Fuels (IGF Code, in development, will be referenced within SOLAS) including requirements for the construction and operation of gas-fuelled ships.

The Emission Control Areas established so far are mentioned below (Table 3).

Table 3: Established ECAs

<p>The ECAs established are:</p> <ol style="list-style-type: none">1. Baltic Sea area – as defined in Annex I of MARPOL (SO_x only);2. North Sea area – as defined in Annex V of MARPOL (SO_x only);3. North American area (entered into effect 1 August 2012) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x and PM); and4. United States Caribbean Sea area (entered into effect 1 January 2014) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x and PM).

It is increasingly becoming apparent to the shipping industry that disparity between standards in northern Europe / North America and China or other parts of the world cannot continue for long. While established ECA's and other initiatives are slashing harmful shipping emissions, the shipping sector accounted for 8.4% of China's sulphur dioxide emissions and 11.3% of its nitric oxide in 2013; an issue which is set to be addressed at all possible levels over the next ten years.

1.4 PORTS

Emissions from ships have recently received more attention since they have become a significant concern for air quality in harbors and port cities.

Ships have historically been the main polluters in ports (UNCTAD/RMT/2014). For instance, most diesel cars emit on average 0.3 to 0.5 per cent sulphur, whereas marine fuels were until recently capped at 4.5 per cent.

However, ships are mainly maneuvered into position by tugs within the port and therefore ports have some control over the level at which these contribute to the port's carbon footprint. In areas where there is high concern about air pollution, ports have been investing in shore power to reduce the use of vessel fuel while at berth. For example, the ports of Los Angeles and Long Beach have been early pioneers of cold ironing technology^{vii}. Recently in the port of Seattle, for the installation of cold ironing facilities for a cruise ship terminal, costs were estimated at \$1.5 million^{viii} per berth and \$400,000 per vessel (Port Technology International, 2014).

Most shipping emissions in ports will grow fourfold up to 2050 (OECD, 2014). This is the case for CH₄, CO, CO₂ and NO_x-emissions. This would bring CO₂-emissions from ships in ports to approximately 70 million tonnes in 2050 and NO_x-emissions up to 1.3 million tonnes. The level of

PM10 and PM2,5 emissions from ships in ports remains at the level of 2011 emissions and SOx emissions decline slightly compared to the 2011 level.

The growth in most shipping emissions is driven by growing demand for certain commodities and goods fuelled by growth of population, economy and trade.

The levels of SOx and particulate matter are not expected to increase up to 2050, due to regulations that will come in force in the coming years as I previously mentioned. These measures should evidently be implemented and the implementation should be controlled, so that the emission reductions will take place. Substantial decreases of SOx and PM would be possible by extending the boundaries of existing ECAs and by introducing new ECAs (OECD 2014).

Mitigating shipping emissions in ports necessitates different levels of intervention, ranging from the level of local authorities to intergovernmental cooperation. Given the nature of the shipping industry, some environmental impacts of shipping are best tackled at the global level. Self-regulation of ports can work, but in most cases, external pressure is needed (OECD 2014).

Various policy instruments have so far been used to help reduce emissions at ports:

Port regulations have so far covered vessel speed reductions in proximity of the port and mandatory fuel switches. Incentives applied by ports include lower tariffs for ships that use cleaner fuels, are more energy efficient or reduce their speed when close to a port.

Various ports have introduced environmentally differentiated port dues, based on the environmental ship index (ESI). The effect of these incentives is for the moment fairly small, as the number of vessels that qualify for reduced port dues is limited.

Voluntary fuel switch programmes are applied in various ports and provide incentives to shipping lines to use low sulphur fuel. These incentives are either in the form of compensations to shipping lines for the additional fuel costs due to their fuel switches, or lower port dues and tariffs (Merk 2013).

Only recently, maritime associations in Germany^{ix} called for legal standards in ports, as well as subsidies for LNG installations since LNG as fuel in the shipping industry has great potential when

it comes to reducing emissions in coastal areas and ports (LNGWorldNews, 2015).

Only recently, China's Ministry of Transportation issued a "*Ship and Port pollution prevention special action plan (2015-2020)*", which includes amongst its provisions promoting the establishment of ship air pollutant emission control areas (ECAs), and calls for active promotion of LNG fuel applications. By end of 2016, LNG wharf design specifications for LNG bunkering will be drawn up. By the end of 2017, a revision of the country's oil and gas emission-related standards will be completed. By 2020, ships using the bustling Pearl River Delta, Yangtze River Delta and Bohai Economic Rrim (which services Beijing, Tianjin and other major cities) will be emitting 65% less sulfur oxides, 20% less nitrogen oxides and 30% less particulate matter compared with 2015. Modification of existing ships must be completed by the end of 2020, when China proposes these areas become recognized emission control areas.

Part Two examines the reasons reducing shipping emissions is important and how it is being brought about, firstly in North America and northern Europe through new regulation for emissions control.

PART 2: NEW REGULATION FOR EMISSIONS CONTROL

2.1 NEW REQUIREMENTS RELATING TO SULPHUR EMISSIONS

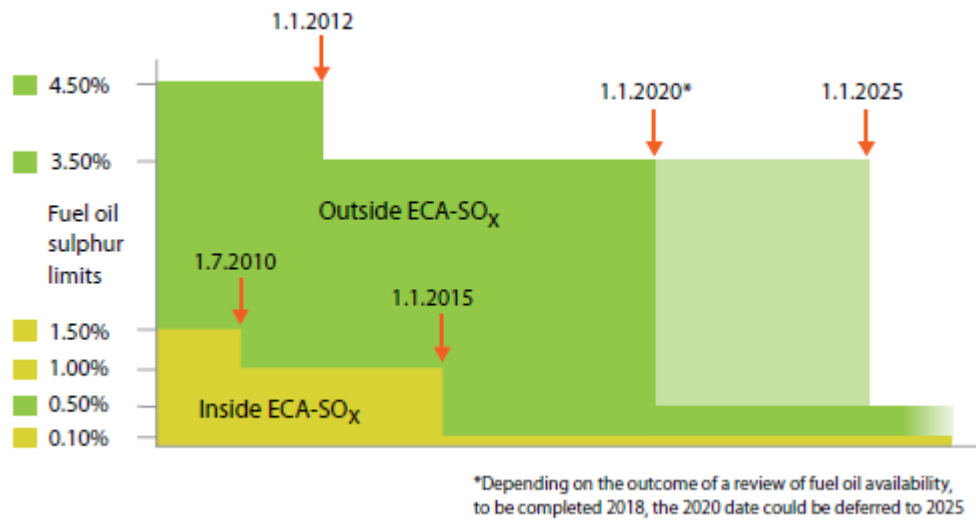
Ships trading in designated emission control areas have to use fuel oil on board with a sulphur content of no more than 0.10% from 1 January 2015, against the limit of 1.00% in effect up until 31 December 2014.

The interpretation of “fuel oil used on board” includes use in main and auxiliary engines and boilers. Exemptions are provided for securing the safety of the ship or saving life at sea, or as a result of damage to a ship or its equipment. Also, provisions for trials for ship emission reduction and control technology research provide for a time limited exemption.

The stricter rules come into effect under the International Convention for the Prevention of Pollution from ships (MARPOL) Annex VI (Regulations for the Prevention of Air Pollution from Ships), specifically under regulation 14, which covers emissions of Sulphur Oxides (SO_x) and particulate matter from ships. These requirements were adopted in October 2008 by consensus and entered into force in July 2010. Currently, MARPOL Annex VI has 77 Parties, representing 94.77% of world merchant shipping tonnage.

Figure 1 (below) outlines the enforcement of sulphur limits in shipping from the present through to 2025. Further below (Table 4) Sulphur Emission Controls inside and outside ECAs are outlined while Table 5 provides an overview of Committed Environmental Legislation enforced from 2011 through to 2016.

Figure 1: MARPOL Annex VI regulations and enforcement of sulphur limits with respective timelines



Source: LNG-fuelled deep sea shipping: The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025 (August 2012) - Lloyd’s Register

The emission control areas established under MARPOL Annex VI for SO_x are: the Baltic Sea area; the North Sea area; the North American area (covering designated coastal areas off the United States and Canada); and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands) (see Table 3).

Table 4: Sulphur Emission Controls

Outside an ECA established to limit SO _x and particulate matter emissions	Inside an ECA established to limit SO _x and particulate matter emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020*	0.10% m/m on and after 1 January 2015

Source: IMO

*depending on the outcome of a review, to be concluded by 2018, as to the availability of the required fuel oil, this date could be deferred to 1 January 2025.

Table 5: Committed Environmental Legislation

NEW INTERNATIONAL LEGISLATION ON MARITIME ENGINE EMISSIONS FOR 2010–2020							
Enforcement	Reference	Legislation	Legislator	Area	Target	Consequences	Ship owner's typical options
01.01.2011	IMO Annex VI	Reduction of NO _x to Tier II level, approx. 20% below current Tier I level	IMO	Global	Newbuilds	Special engines or exhaust gas purification. Higher voyage and capital costs	a) Choose (or modify to) low-NO _x engines b) Use Tier I rated engines with SCR, EGR, HAM, water emulsion etc. c) Use LNG as fuel
01.01.2012	IMO Annex VI	Sulphur content in fuel <3.5%, progressively towards 0.5% sulphur by 2020 (maybe later)	IMO	Global	Sailing and new ships	Potentially higher voyage costs	a) By 2012: Change to 3.5% sulphur fuel. Towards 2020: Low-sulphur fuel or conventional fuel with scrubber is required b) Use LNG as fuel
01.08.2012	IMO Annex VI	Sulphur content in fuel <1.0% in ECAs	IMO	ECA	Sailing and new ships	Possible equipment adaptations, or exhaust gas purification. Higher voyage costs	a) Use <1.0% sulphur fuel b) Use >1.0% sulphur fuel together with scrubbers c) Use LNG as fuel
01.01.2015	IMO Annex VI	Sulphur content in fuel <0.10% in ECAs	IMO	ECA	Sailing and new ships	Higher voyage costs, possible equipment adaptations or exhaust gas purification	a) Use <0.1% sulphur fuel b) Use >0.1% sulphur fuel together with scrubbers c) Use LNG as fuel
01.01.2016	IMO Annex VI	Reduction of NO _x to Tier III level in ECAs, approx. 75% below Tier II level	IMO	ECA	Newbuilds	Exhaust gas purification (unless engines are significantly improved). Higher voyage and capital costs	a) Install exhaust gas purification such as SCR, or other possible measures. b) Use LNG as fuel

Source: DNV (2011) *Greener Shipping in North America*

2.2 MEETING NEW REQUIREMENTS

There are thousands of ships currently sailing the world's oceans which were not built according to today's modern standards for efficiency (Germanischer Lloyd 2013b).

Ships can meet the new requirements by using low sulphur fuel oil such as Marine Gas Oil (sometimes called distillates). An increasing number of ships are also making use of gas as a fuel as this contains no sulphur and when ignited leads to negligible Sulphur Oxide emissions. This has been recognized in the development by the IMO of the International Code for Ships using Gases and other Low Flashpoint Fuels (IGF Code), which was adopted in 2015.

The IGF Code provides mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels, focusing initially on liquefied natural gas (LNG), to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved.

The Code addresses all areas that need special consideration for the usage of low-flashpoint fuels, based on a goal-based approach, with goals and functional requirements specified for each section forming the basis for the design, construction and operation of ships using this type of fuel.

Under “Equivalent” provisions also adopted in 2008, ships may meet the SO_x requirements by using approved equivalent methods, such as an apparatus or piece of equipment (for example, Exhaust Gas Cleaning Systems or “scrubbers”, which “clean” the emissions before they are released into the atmosphere). In this case, the equivalent arrangement must be approved by the ship’s Administration (the flag State) that is a State Party to MARPOL Annex VI.

New requirements are gradually but steadily being met and the shipping industry is responding effectively to the new regulatory framework. Most vessels can consume low sulphur fuels, or can be adapted to consume such fuel relatively cheaply (Steamship Mutual 2015).

Before the lower 0.1% sulphur content requirement came into effect at the start of 2015, there were concerns that there would not be sufficient low sulphur fuel available at bunkering ports in or near to ECAs. However these concerns proved to be unfounded, and low sulphur fuels have been readily available in these areas (Steamship Mutual 2015b).

While a shipowner is obliged to comply with the MARPOL regulations, it is the time-charterer who pays for the fuel consumed, and a time-charterer will usually want the ship to perform as efficiently and economically as possible, by consuming the more expensive low sulphur fuel only when the ship is required to do this, within the ECAs.

According to P&I Club Steamship Mutual (2015b):

MARPOL requires vessels to be in compliance at all times when sailing in the ECA, therefore a vessel needs to have compliant low sulphur fuel onboard, and to

have changed over to low sulphur fuel in sufficient time to ensure that compliant fuel is being consumed before the vessel enters the ECA. If a charterer gives an order to sail to an ECA, then the Charterer will need to ensure the ship has enough low sulphur fuel onboard to use while in the ECA, or will need to supply low sulphur fuel before the vessel reaches the ECA. Any Charterer's orders to sail into or through an ECA on high sulphur fuel are probably unlawful since that order would require an Owner to break international and national regulations, and an Owner would be entitled to call on the Charterer to provide fresh orders which, dependent on what quantities of low sulphur fuel were onboard, might require the vessel to divert to stem low sulphur fuel before the ECA.

Even if a vessel is not calling at any port in an ECA, the vessel must still comply with its requirements when passing through an ECA.

While the time charterer is obliged to provide compliant fuel, the care and management of fuel onboard remains the responsibility of the Owner.

Many vessels, whether or not operating under time-charter, are expected to change over from low sulphur fuel to cheaper high-sulphur fuel and back to low sulphur fuels on a regular basis as they leave or enter ECAs. Whilst the vessel ought to be able to do this, the vessel's engine might need different lubricating oils, to be compatible with the different fuels and advice should be sought from the engine manufacturer.

The vessel's staff can face other technical challenges in changing between different fuels, with different temperatures, viscosities, or other incompatibility between fuels.

Many vessels trading under the new regime were built before it was necessary to have both low sulphur and high sulphur fuel onboard and, therefore, have been adapted to trade under the new requirements by having some of their fuel tanks dedicated to low sulphur fuel. This might reduce the range of the vessel, with the effect that the time-charterer has to arrange more bunker stems.

It is probably uneconomic to change storage tanks from low sulphur to high sulphur oil on a regular basis if the vessel is frequently employed in trades through or in and out of ECAs (with the corresponding risk of contaminating low sulphur fuel).

2.3 CONTROLS & SANCTIONS

Flag States must issue an International Air Pollution Prevention (IAPP) Certificate to the ship. This includes a section to state that the ship uses fuel oil with a sulphur content that does not exceed the applicable limit value as documented by bunker delivery notes; or uses an approved equivalent arrangement.

Ships taking on fuel oil for use on board should have a bunker delivery note, which states the sulphur content of the fuel oil supplied. Samples may be taken for verification.

Port and coastal States can use port State control to verify that the ship is compliant. They could also use surveillance, for example air surveillance to assess vessel smokestack plumes, and other techniques to identify potential violations.

Sanctions are established by individual Parties to MARPOL, as flag and port States. There is no established fine or sanction set by IMO – it is down to the individual State Party.

2.4 THE E.U. & NEW REGULATION

Regarding GHG emissions, the EU has set specific targets and is discussing various policy development mechanisms. For non-GHG emissions, the EU generally follows the standards set by the IMO.

The EU has set a target to reduce GHG emissions by 20% by the year 2020, compared to 1990 levels, and is aiming to reduce shipping emissions by 40-50% by 2050. To achieve these targets, the EU supports the implementation of an emissions trading scheme for the shipping industry.

EU co-legislators reached an informal agreement on the Commission proposal for a Regulation on the monitoring, reporting and verification (MRV) of CO₂ emissions of maritime transport.

The agreement paves the way for a European MRV system that will become operational as of 2018, applying to ships above 5000 GT arriving and departing from EU ports, regardless of their flag and ownership.

The Regulation is meant to be a stepping stone towards a global MRV instrument. Apart from data on CO2 emissions and distance sailed, the negotiators agreed that the Regulation will also require ships to report cargo-related information.

The MRV requirements will apply to CO2 emissions arising from voyages to, from and between EU ports. All ships over 5,000 gross tons will be covered, with the exception of:

- fishing vessels (catching and/or processing),
- warships,
- naval auxiliaries,
- wooden ships of a primitive build,
- ships not propelled by mechanical means, and
- government ships used for non-commercial purposes.

The European Commission would have to review this regulation in the event that an international agreement to reduce greenhouse gas emission from maritime transport is reached, in order to align it with that international agreement. The regulation came into force on 1 July 2015.

With regard to sulphur emissions, IMO standards have been incorporated into EU laws, and member states are required to transpose the regulations into national laws.

2.5 OTHER AREAS

Outside the emission control areas, the current limit for sulphur content of fuel oil is 3.50%, falling to 0.50% m/m on and after 1 January 2020. The 2020 date is subject to a review, to be completed by 2018, as to the availability of the required fuel oil. Depending on the outcome of the review, this date could be deferred to 1 January 2025^x.

The lack of regional mitigation measures has made the need to extend ECAs further pressing. In

order to reduce shipping emissions worldwide, stricter regulations will be needed, including alternative fuels or power sources, such as liquefied natural gas; operational measures, like hull and propeller conditions or weather routing; technical measures, such as improved engines; and structural changes, like port efficiency or slow-steaming (OECD 2014).

In August 2015 the Chinese government took several important steps to control emissions from shipping activities, which until now have been virtually unregulated.

First, the National People's Congress adopted a number of amendments to China's 15-year old Air Pollution Prevention and Control Law. These provisions, for the first time, provide a clear legal foundation for the government to tackle shipping emissions (see Appendix).

The amended Air Pollution Law now requires the fuel used by ships while at berth to comply with government-set requirements for meeting emission standards. All new terminals should provide shore side electric power so ships can turn off their diesel engines while at berth. Vessels must be certified for meeting national air emission standards in order to operate in China. The law prohibits the sale or import of nonconforming marine fuels and imposes heavy fines on violators.

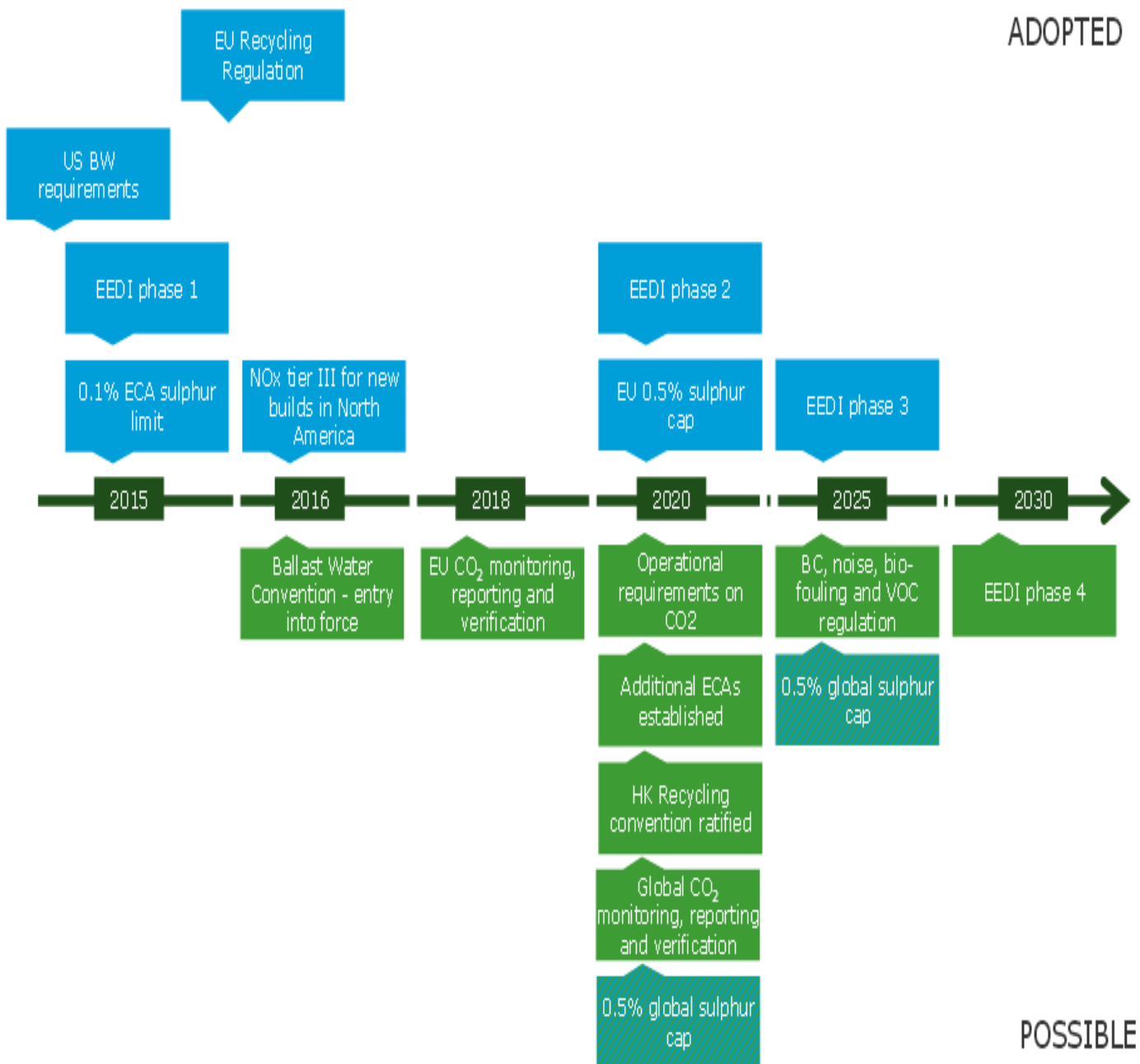
Furthermore, the law provides clear legal authority for national government's transport authority, i.e. China's Ministry of Transport (MOT), to set more stringent air pollution requirements for key port regions by designating them as Emission Control Areas (ECAs).

The Chinese Ministry of Transport has also issued a detailed Shipping and Ports Pollution Prevention and Control Implementation Plan. This is the first time that such concrete action has been decided by Chinese authorities to address air emissions from ships and port activities. The implementation plan includes specific goals and timetables for setting up emission control zones around key port regions, constructing shore power facilities and promoting the use of liquid natural gas (LNG) by vessels (See Appendix).

The following figure (2) summarizes events to date and outlines possible developments towards 2030 in the adoption of legislation supporting the use of clean fuels:

Figure 2: Legislation supports the use of clean fuels

ADOPTED



POSSIBLE

Source: DNVGL^{xi}

Implications for shipping from emissions reduction (in terms of infrastructure and economic effects) are examined in Part Three.

PART 3: IMPLICATIONS FOR SHIPPING FROM EMISSIONS REDUCTION

3.1 NEW REGULATION AND ITS INFRASTRUCTURAL IMPLICATIONS FOR SEAPORTS

Shipping emissions in ports are substantial, accounting for 18 million tonnes of CO₂ emissions, 0.4 million tonnes of NO_x, 0.2 million of SO_x and 0.03 million tonnes of PM₁₀^{xii} in 2011. Around 85% of emissions come from containerships and tankers (OECD 2014). Containerships have short port stays, but high emissions during these stays.

Most of CO₂ emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). European ports have much less emissions of SO_x (5%) and PM (7%) than their share of port calls (22%), which can be explained by the EU regulation to use low sulphur fuels at berth (OECD 2014).

Introduction of new IMO regulation regarding sulphur content in ship's fuel and connecting with that development of such solutions as scrubbers and LNG as a ships' fuel will involve simultaneously development of specialized facilities in ports.

In the case of scrubbers, the waste generated during the whole process should be handled properly and not be discharged at sea. This means that scrubbers must be stored on board and then delivered to a shore reception facility.

Regulation 17 of MARPOL Annex VI requires port reception facilities for scrubber residues. However, the infrastructure for scrubber waste disposition is not yet in place and no regulations exist that regulate the port's responsibility to handle such waste.

In July 2011, the IMO issued a resolution giving guidelines for reception facilities under MARPOL Annex VI. It is also necessary to revise Directive 2000/59/EC of the European Parliament and the Council of 27 November 2000 on port reception facilities for ship generated waste and cargo residues. Pending the revision, Member States should ensure, in accordance with their international obligations, the availability of port reception facilities adequate to meet the needs of ships using exhaust gas cleaning systems.

Other needed investments in SECA seaports are connected with use of LNG as a ships' fuel. To offer LNG as a fuel to ships, infrastructure for distribution of LNG fuel must be established. Three basic solutions can be implemented (EMSA 2013):

- Tank truck to ship bunkering
- LNG terminal to ship via pipeline bunkering
- Ships to ship bunkering

Since LNG bunkering isn't yet mainstream in the industry, most empirical research into the development of using LNG as fuel for vessels is limited mostly to regions in northern Europe. The two first out of the above three options are now used in Norway. In the first case, bunkering takes place at berth from tank trucks. Truck capacity varies from 40 to 80 m³ of LNG, depending on tank design and regulations. This solution makes it possible to bunker the ships in any localization, however, it takes a lot of time. Bunkering process from one 55 m³ tank truck last about one and a half hour. Which means that bunkering process for typical LNG passenger ferry operated in Norway that has two tank of capacity of 120 m³ last about 6.5 hour. Due to duration of bunkering, this solution is suitable for small volumes, up to 100-200 m³, of bunker fuel.

In the second case, bunkering process takes place at berth from port facilities. Bunkering can be carried out at high loading rates and large volumes, which means that bunker times can be kept short. Terminal tanks may vary, from very small (20 m³) to large (50,000 m³) depending on requirements, needs, available space etc. Such LNG terminals could be supplied by a small scale LNG shuttle vessel (e.g. 20,000 m³) from local LNG import terminal which would serve as a hub to such bunker stations. Berth access and distance between source and receiving vessel are essential factors in the success of pipeline to ship solutions.

The main limitations of the solution relate to the challenges associated with long liquid LNG pipelines. For longer distances, it is difficult to fuel LNG directly from LNG terminals, from technical, operational and economic perspectives. This implies that storage tanks must be situated in close proximity to the berths where bunkering operations are performed.

The third option is not used yet. At present works are being carried out to create rules that regulate the ship-to-ship bunkering operations. Bunkering could be performed alongside quays, but it is also possible to bunker at anchor or at sea during running. Typical capacities of LNG bunker vessels

may range from approximately 1,000 to 10,000 m³. Small vessels or barges can also be used in some ports with capacities of less than 1,000 m³. Ship-to-ship bunkering is expected to be the bunkering method for vessels that have bunker volumes of 100 m³.

Several European ports have begun promoting the use of liquefied natural gas (LNG) as a ship fuel. Bremenports, which is responsible for the management and development of Bremen and Bremerhaven, has decided to actively support the future use of LNG. In addition to the construction of an LNG depot in 2011, one of its main strategies is to use LNG itself, through the creation of ship services powered by LNG in 2012. It is hoped the use of LNG by the service fleet will set a precedent for other users in the port, and Bremenports has a policy of providing technical expertise on these matters to facilitate the popularisation of such technologies. The ports of Rotterdam and Gothenburg already run incentive schemes that subsidise the use of LNG by ships. Both ports are also investing in LNG facilities. Gothenburg and Rotterdam have already begun co-operating on standardisation efforts to ensure that LNG is handled in a uniform manner and to speed up the development and adoption of LNG as a fuel (Merk, 2013). Elsewhere, most notably China is also looking to create 23 LNG import terminals as part of its energy switch away from coal, which will also help developing gas bunkering infrastructure in the country (Lloyds List 2015).

Demand for LNG bunkering infrastructure at ports will only fully materialize if adequate supply exists, conversely the supply will only materialize if developers of the supply infrastructure are sure that the demand will materialize.

In terms of financing, investments in LNG bunkering infrastructure are expected to be private sector financed in the main although some port authorities will initiate projects and there is a case for public financial support in the early stages of network development (Danish Maritime Authority 2012).

Regarding LNG strategy and infrastructure, economic aspects such as investment as well as operational costs will most likely decide the future LNG strategy for ports. The Danish Maritime Authority (2012) summarizes the economic criteria for LNG bunkering as follows:

- A. Investment costs:** Investments in the form of quays, supervision and broadening of fairways, etc. Positive affecting factors can be dedicated partners, e.g. a region/country that can provide part of the investment costs (conduct construction work for ports, etc). Loan

terms may differentiate depending on which country a terminal will be built in.

- B. Operational costs:** Different operational costs (for example personnel costs, fee for bunkering, port fees and fairway dues) vary depending on ship type, bunkering location, etc.
- C. Reasonable price of LNG:** Most advantageous prices for conventional bunker today are a consequence from lower distribution costs and large volumes. It is assumed to be the same for LNG.
- D. Incentive of investments:** Port should have finances for investments, risks during financial crises, etc.
- E. Financing:** Banks knowledge for judging feasibility of LNG bunkering is probably low and depends on how sponsors are integrated in the LNG value chain and how they plan to utilize this capacity.

In terms of a potential network development of LNG bunkering points, its most likely path is the following (Danish Maritime Authority 2012):

1. Major bunkering ports with existing or planned LNG facilities;
2. Bunkering ports within range of bunkering vessels;
3. Ports with substantial captive traffic – Ro-Ro, RoPax, liners, supply vessels, fishing, tugs;
4. Ports with modest captive traffic but strong land-based demand;
5. Bunkering ports without nearby LNG.

3.2 ECONOMIC EFFECTS OF NEW IMO REGULATION

Changes to regulation are generating new opportunities for companies that offer solutions – energy efficient engines, designs, coatings; low-sulphur fuel producers; scrubber manufacturers; and LNG producers – and therefore for investors as well.

Predicting how bunker fuel prices will change in future is a matter of pure speculation as the price levels are influenced by a series of different factors, e.g.: supply of crude oil, demand, development of alternative fuels, geopolitical developments (Baltic Ports Organization, 2012).

Not all ships will be similarly affected by the increased fuel prices. Impact depends on the share of fuel costs out of the overall transport cost for the specific ship type.

During the last dozen or so years, the cost of ships' fuel has been characterized by large fluctuations. One important factor is that there are today huge differences in LNG prices.

As an example the prices in Japan and South Korea are about USD 13,50-13,80/mill BTUs and in Europe USD 11,77. The wholesale price in US is as low as USD 2,50-3,00/mill BTUs. According to Kanfer Consulting & Shipping (April 2013), this is not a price that we can expect globally in years to come.

Global price disparity is a concern. Pricing is generally based on supply and demand, but other factors such as politics, but also cost and competition need to be taken into consideration. Now there are huge reserves of gas in the world and some are calculating that there is sufficient gas for at least 250 years. If so, there are reasons to believe that prices should remain low.

Shipping companies agree that the shift to such technologies will result in increased costs. According to Maersk, opting for low-sulphur fuel will result in an additional USD 250 million in fuel costs. Shipping companies are likely to pass on this increase in costs to customers, and some may request financial support from national governments (Sustainanalytics 2013).

However there are good reasons to believe that the demand for LNG would increase considerably over years. However there are even better reasons to believe that US will start export of shale gas. The US has huge reserves of shale gas and so has China. The reserves in US, Canada and China is of a size that will prevent countries like Russia and Persian Gulf countries (that today has more than 60% of the known/available global natural gas reserves) from dictating higher prices for the gas they export to Europe. With more shale and natural gas being available, better access to LNG globally together with more competition, the price will remain low for foreseeable future.

The new regulations on shipping emissions could also trigger an increase in demand for a host of companies. Companies such as Shell for example, through subsidiary Gasnor, could benefit if the shipping industry decides on LNG as its fuel (Sustainanalytics 2013). Gasnor is the market leader of small-scale LNG supply in Norway, which is the most developed LNG market in the world. Shell is followed by ExxonMobil as the largest LNG producing company in the world (Reuters 2013). Some predictions estimate that demand for LNG bunker fuel would increase by 25 million tonnes if 10% of the world's shipping fleet were to adopt LNG fuel by 2025 (Tri-Zen 2012).

LNG bunkering (procedures, regulations, safety) is presented in the next Part of this dissertation in order to understand the specifics of using LNG as a fuel for shipping and assess advantages and concerns for industry players.

PART 4: LNG BUNKERING

Transport demand has strongly increased at or above the GDP growth rate, and maritime trade has become the most important mode for merchandise transfer. Today, almost 90% of the world goods are carried by sea and maritime transport account for over 90% of European Union external trade and 43% of its internal trade (UNCTAD, 2007).

As seaborne trade grows, the shipping industry is increasingly exploring options to reduce emissions or to produce cleaner transportation fuel as an essential step to decrease pollution emitted by marine diesel engines. LNG bunkering will play an important role in developments.

According to the International Chamber of Shipping (ICS, 2014):

“LNG could be an interim solution until a viable alternative to fossil fuels is eventually found, especially for shorter voyages provided that supply infrastructure can be developed”.

A growing number of vessel owners, bunker suppliers and ports are willing to embrace the clean fuel, or at least willing to look at it as an option (Lloyds List 2015b). This is not surprising: both economic and regulatory factors are supporting an LNG-fuelled future. The question is just whether they are strong enough.

Naturally, as the new emission control area rules in the North Sea, the Baltic Sea and North American waters require vessels to use 0.1% sulphur bunker fuel instead of 1% sulphur grade, shipping stakeholders in Europe and the US are among the keenest to discuss LNG bunkering. Asia, the world’s largest bunkering market, still embraces 3.5% sulphur fuel, so there are fewer incentives to invest in LNG facilities (Lloyds List 2015b).

There is evidence currently that there are various types of LNG facilities already available and potential for further expansion. The types of facilities that may provide LNG fuel include (ABS 2014):

- Existing LNG import facilities
- Proposed LNG export facilities

- Existing LNG peakshaving/satellite facilities
- Existing and proposed liquefaction facilities supporting highway, heavy equipment, and rail markets
- Proposed bunkering facilities with liquefaction process
- Proposed bunkering facilities supplied via trucks/transportation containers

Evidence presented below shows that LNG could be much more than a small scale *interim solution* as great strides are being made towards developing technology and the framework required that will allow LNG to be a viable longer term option.

4.1 BASICS OF LNG & USING GAS AS A FUEL

Liquefied natural gas LNG is natural gas that has been temporarily converted to liquid form for efficient storage and transport. Natural gas becomes liquid at -163°C where it takes up only 1/600 of the space of the gas. This source of energy, consisting mainly of methane, originates from multiple gas fields worldwide, and global reserves are still rich. Natural gas is mostly used in power generation, and in industrial and domestic use.

Natural gas contains a number of different compounds of which the largest constituent is methane. There will also be ethane, propane, butane, nitrogen and carbon dioxide along with a few other compounds which have to be removed from the gas before use such as hydrogen sulphide.

Methane is a good choice in terms of marine fuel due to a number of important economic, environmental and practical reasons for its use. Most notably, reserves worldwide are much higher than crude oil (the IEA estimates there is presently enough for 250 years' consumption); pricing levels are attractive; CO₂ emissions are considerably lower than from liquid hydrocarbons; methane doesn't contain sulphur; it is clean burning; it offers reduced maintenance, reduced handling and treatment on board (Draffin, 2013).

Natural gas is an internationally traded commodity and is priced in accordance with its volume or its energy content.

The dominant market is the United States and the traditional pricing point is Henry Hub, a distribution point in Louisiana which forms the basis of the contracts traded on the New York

Mercantile Exchange (NYMEX). The price is energy content related and quoted in US Dollars per 10,000 million British thermal units (MMBtu).

Using energy content allows for the variation in energy content of gas from different sources and can be related simply to the price of LNG from different sources.

The first cargo of LNG was transported in 1959. Since then LNG has developed into the transport mode for about 20% of the international trade of natural gas. The rest is transported by pipeline.

The projections for the future indicate that as much as 50% of natural gas will be transported as LNG because the remaining gas reserves are located further away from main consumption areas, and because it is becoming increasingly expensive and difficult to construct new pipelines. This, in addition to significant growth in natural gas demand, may lead to a boom in LNG trade (DNV 2011).

When it comes to using gas as a fuel, to ensure a competitive fuel supply, LNG bunkering must be possible for each type of gas-fuelled vessel under the same conditions as bunkering Heavy Fuel Oil (HFO). This includes the safe bunkering of LNG during cargo loading and unloading, as well as during passenger embarking and disembarking operations (EMSA 2013).

The supply chain for LNG as ship fuel and bunkering remain issues that are currently being thoroughly researched and documented. LNG suppliers are slowly becoming convinced that this technology will take off, and potential LNG users are discovering that LNG will be made available at an attractive price and at convenient locations.

Current developments show that access to LNG bunkering is developing. A number of LNG ports offer or plan to offer LNG facilities, particularly in Northern Europe (Germanischer Lloyd 2013a):

- In 2011, a new LNG terminal by Linde was officially opened in Nynäshamn, south of Stockholm.
- Vopak teamed up with Swedegas to develop the LNG terminal in Gothenborg.
- Vopak and Gasunie are developing an LNG Break Bulk facility in the Port of Rotterdam, as a spin-off from Gate terminal.

- The Netherlands is implementing four different projects along the Rhine to provide LNG refueling stations for inland vessels.
- Gasnor will soon be making LNG available at the German port of Brunsbüttel. Initially, the company will supply LNG by truck and then possibly build a small terminal in the future, provided that demand develops accordingly.
- GL is currently working with the Hamburg Port Authority to explore options for offering LNG as ship fuel in Hamburg.
- An LNG bunker facility is planned for Singapore at the end of 2014 to serve small-scale distribution in Asia.
- Bremenports has announced that an LNG bunker station will be built in Bremerhaven in cooperation with Bomin Linde.

Lloyd's Register (2012) categorizes New York, Houston, San Francisco and Los Angeles as tier 1 ports for developing LNG fuel, meaning they fulfill at least two of the primary considerations:

- They are known bunkering ports.
- They are known to be looking at their potential as LNG bunkering sites.
- The supply of LNG is within a 50 mile radius.
- The port is along a main deep-sea trade route.

4.2 BUNKERING PROCEDURES

Small-scale LNG carriers (between approx. 10,000 m³ and 20,000 m³ loading capacity), built for regional supply, will be the link between liquefaction plants or re-export terminals and dedicated bunkering locations (Germanischer Lloyd 2013a). A number of small LNG carriers are already in service, and further newbuildings are under construction.

The last step of supplying LNG to the end user will require LNG bunker vessels, which are still to be built. This involves the direct bunkering of gas-fuelled ships, using gas carriers or special barges

for refueling, provided they are properly equipped and are able to carry enough gas for large ships (Germanischer Lloyd 2013a).

At the moment, bunkering takes place at specially equipped gas terminals during dedicated refueling timeslots for the limited number of vessels operating on LNG as fuel, and the vessels are taken out of service for bunkering. However, several bunker vessel designs for LNG feeder carriers, in accordance with the IGC Code requirements, have been published and can be built today.

Using gas as a fuel for ships means it usually is supplied directly to the combustion process by pipe at a temperature and pressure appropriate for the type of equipment being used. The gas is inflammable and can form explosive mixtures with air.

The standard transfer method for ships using LNG as fuel uses flexible cryogenic hoses which connect either shore tanks, road tankers or the barge (the supply sources) to the receiving ship. Ship to ship LNG transfers are also used as a bunkering method, also using cryogenic hoses.

Most bunkering procedures have been developed from automotive and industrial practices. The storage of LNG (both at sea and land storage) involves, however, a considerable amount of fundamental risks.

The use of methane for non-LNG tankers is still in its infancy. As the number of LNG-fuelled vessels rises, LNG trained staff will be needed in order for LNG bunkering to be carried out with a very high degree of operational safety. Standardization of equipment and procedures across the full range of ships using LNG as fuel is the most rational solution (Germanischer Lloyd 2013a).

4.3 REGULATIONS

4.3.1 *IMO*

The IMO has issued a code for the construction and operation of vessels carrying liquefied gases in bulk, the IGC Code. It is also developing rules for the use of gas fuel on ships, the IGF Code. Although this is still under development, the IMO has published an interim guide for these vessels. All these rules are under the control of the Maritime Safety Committee (MSC) and are part of the International Convention for the Safety of Life at Sea (SOLAS). This dissertation examines them

briefly further below.

4.3.2 IGC CODE

The most recent edition of the IGC Code was published in 1993 and currently incorporates amendments from 1994 and 1996. The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (the IGC Code) was agreed by the Sub-Committee on Bulk Liquids and Gases (BLG) when it met for its 17th session in February 2013.

The IGC Code was first adopted in 1983, to provide an international standard for the safe carriage by sea of liquefied gases (and other substances listed in the Code) in bulk, by prescribing the design and construction standards of ships carrying such cargoes, and the equipment they should carry.

4.3.3 IGF CODE

The draft International Code of Safety for Ships using Gases or other Low flashpoint Fuels (IGF Code), along with proposed amendments to make the Code mandatory under SOLAS, were agreed by the inaugural session of the IMO Sub-Committee on Carriage of Cargoes and Containers (CCC 1) in September 2014.

The basic philosophy of the IGF Code is to provide mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low flashpoint fuels, such as liquefied natural gas (LNG), to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved.

The Code addresses all areas that need special consideration for the usage of low flashpoint fuels, based on a goal-based approach, with goals and functional requirements specified for each section forming the basis for the design, construction and operation of ships using this type of fuel.

It was agreed that the new IGF Code should apply to new ships and to existing ships converting from the use of conventional oil fuel to the use of gases or other low-flashpoint fuels, on or after the date of entry into force of the Code. The IGF Code would not apply to cargo ships of less than 500 gross tonnage, but the provisions of the IGF Code could be applied to such ships on a voluntary basis, based on national legislation.

Since the draft IGF Code focuses, as a first step, on the specific requirements for ships using LNG as fuel, the Sub-Committee also agreed a work plan for the next phase of development of the IGF Code, to take account of the need to consider future proposals for the use of additional fuels for inclusion in the Code. The IGF Correspondence Group was re-established to: further develop guidelines for ships using ethyl or methyl alcohol as fuel; further develop measures for fuel cells for inclusion in the IGF Code as and when appropriate; further develop measures for ships using low-flashpoint diesel oil for inclusion in the IGF Code as and when appropriate; and submit a report to CCC 2 (scheduled to meet in September 2015).

4.3.4 SOLAS

The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The Convention is linked to the bunkering of ships in the use of fuel on ships with reference to the flash point of fuels and the provision of Material Safety Data Sheets (MSDS) for fuel supplied. The regulations concerning the use of gaseous fuel for LNG carriers is governed under SOLAS by the IGC Code and the use of gaseous fuel on non-LNG tankers is governed by the IGF Code.

4.4 ADVANTAGES AND CONCERNS

Reliable and safe concepts, established legislation, the regulatory framework and necessary competences, knowledge and skills are the main requirements to develop a LNG bunkering infrastructure – provided LNG is available, access to capital is given and the public is informed (DNVGL, 2014).

While the shipping industry could use mineral oil with low sulphur content or fit scrubbers into exhaust gas systems, LNG as a shipping fuel is regarded as one of the most promising options to meet the new requirements.

LNG as a fuel has virtually no sulphur content. Additionally, its combustion produces low NO_x (80% less nitrogen oxides) compared to fuel oil & marine diesel oil. LNG is also priced lower than global bunker fuel although plummeting oil prices and how oil production will develop in 2015 will impact on the attractiveness of LNG bunkering.

LNG is lower in controlled pollutants, containing 80% less nitrogen oxides (for Otto-Cycle engines) than conventional maritime fuels. LNG-fuelled ships also produce 20% less carbon dioxide, according to BIMCO.

Due mainly to lack of widespread, ready-to-use infrastructure, conventional oil-based fuels will remain the main fuel option for most vessels in the near future, and, at the same time, the commercial opportunities of LNG are interesting for many projects. While different technologies can be used to comply with air emission limits, LNG technology is the only option that can meet existing and upcoming requirements for the main types of emissions (SO_x, NO_x, PM, CO₂). According to DNV GL^{xiii}, LNG can be competitive pricewise with distillate fuels and, unlike other solutions, in many cases does not require the installation of additional process technology.

In terms of concerns being raised, the most notable issue is the heavy investment required in ship propulsion & fuel handling systems as well as investment in bunkering facilities that is needed. The development of new international safety regulations will also be required should LNG bunkering take off while availability is also a serious concern.

Furthermore, competition between ship owners will be massively distorted if lack of enforcement allows some in the industry to avoid meeting the new requirements, according to BIMCO.

In addition, limited availability of satellite terminals and bunker barges (floating refuelling stations for LNG) will make it difficult for most ships to switch from traditional liquid fuel to LNG.

Furthermore, compared to other fuels, the combustion of LNG emits significant amounts of another GHG: methane (CH₄) which has a high global warming potential.

Table 6 (below) analyzes the strengths, weaknesses, opportunities and threats of the use of LNG as shipping fuel.

Table 6: SWOT Analysis

Liquefied Natural Gas	
Strength	Weakness
<ol style="list-style-type: none"> 1. Comply with EU regulations 2. Least harmful to the environment 3. Most economically feasible in the long term 	<ol style="list-style-type: none"> 1. Lack of available supply chain and infrastructure 2. High flammability and toxicity 3. Additional investment of 10-50%

	for new vessels
Opportunity	Threat
1. LNG fares better than other technologies economically or technically 2. Stricter regulations come in place	1. Transport shift towards road or rail 2. Infrastructure does not develop 3. LNG fares worse than other technologies economically or technically

Source: Sustainanalytics (July 2013) *Emission Reduction in the Shipping Industry: Regulations, Exposure and Solutions*

Moving ahead on LNG technology requires not just the support of the shipping industry but also the support of political decision-makers (Germanischer Lloyd 2012):

- to establish a roadmap at European level initiated by the European Commission with an indication of the necessary steps to be taken within a clear time frame.
- the roadmap should include amongst other things:
 - development of regulatory measures especially with regard to safety measures;
 - identifying in detail financial means to support the sector such as implementation projects, studies and pilot actions introducing new technologies, innovative infrastructure and facilities supporting the deployment of LNG;
 - creating a one-stop shop for industry, addressing financial support;
 - identifying whether there is a need for further R&D work and / or pilot projects.

Finally, there is also a considerable difference between a small-scale LNG value chain like LNG bunkering and conventional marine bunkering, in that the price of an HFO bunker can be found on the internet for most major ports. Such openness is not present for LNG as a fuel or for LNG in small quantities.

The LNG “prices” that can be found in public sources are not the prices a shipping company would pay for LNG bunkering, but those prices are either at a gas hub or at delivery to an LNG import terminal. They do not include redistribution costs, mark up etc. As a result, the price for a certain amount of LNG delivered to a ship in one port depends heavily on the availability of the

transport infrastructure. This is typical for goods that are non-commoditized.
(DNVGL, 2014b).

However, as LNG fueled shipping is gaining pace, efforts are being made to develop an understanding of future markets. This understanding is guiding today's infrastructure development which, in turn, will establish tomorrow's markets. When an open well-functioning small-scale market is developed prices for LNG as fuel will be found on the web in real-time (DNVGL, 2014b).

4.5 LNG SAFETY

Gas carriers around the world have been using liquefied natural gas (LNG) as part of their fuel source for decades. As previously mentioned in this dissertation, extensive regulation is already in place for the use of LNG as fuel in shipping.

The safety record of LNG carriers is extremely good. Even though most of the principles remain the same, using LNG as fuel for conventional ships introduces new systems on board together with their associated risks. In order to design, build and operate a gas-fuelled vessel in a safe and sustainable way, these risks will have to be thoroughly investigated and minimised.

Important risk-related items to consider include:

- High energy content of the LNG tank
- Explosion hazard in case of gas leakage
- Extremely low temperatures of the LNG fuel
- Location/arrangements of system
- Hazardous vs. non-hazardous spaces
- Inexperienced crew (new fuel source)

The international certification body and classification society, DNV GL, is amongst a host of industry stakeholders setting new rules and forwarding the use of LNG as fuel for non-LNG tankers, always in accordance with the IGF Code mentioned earlier in this dissertation.

New rules build on relevant real life experience as well as risk assessment tools. They contain functional requirements allowing for the ability to consider innovative solutions within the

framework of the rules, but also include clear and prescriptive guidance for building safe gas-fuelled ships with known solutions.

This for instance means more clear guidance for spaces around “new” types of LNG fuel tanks and better requirements for cryogenic fuel piping going through the ship and for fuel preparation spaces. The updated rules also provide more precise certification requirements for components used in LNG fuel ship systems.

Hence, the uncertainties for the owners and yards are reduced, both when looking into standard solutions and more innovative designs. The main outcome is however to more efficiently lower the risks for gas-fuelled ship designs (DNV GL, 2014).

In the final Part of this dissertation, research is presented into the development of the LNG-powered fleet along with an assessment of the economic factors determining the role of LNG in the marine fuels market and the pace at which change is occurring.

PART 5: THE ROLE OF LNG IN THE MARINE FUELS MARKET

5.1 THE LNG FLEET

LNG-fueled ships are not new. Since 1964 almost all LNG carriers, whether using steam-turbines or DFDE and MEGI power plants, are gas-fueled.

The fleet of LNG-fuelled vessels plying the world's oceans comprises passenger ferries, offshore service vessels, coastguard vessels, tankers and many other types. Even a high-speed catamaran with LNG-powered gas turbine is in operation.

Table 7: LNG as a marine fuel – Who is doing it

An Overview

Interest in the use of LNG as a bunker fuel is growing rapidly, not just in ECAs but around the world.

In **Europe**, Norway, the country that pioneered the technology, continues to push forward with more vessels. The European Union (EU), with 28 member states, is attempting to develop a co-ordinated approach to the use of LNG as a marine fuel, with a particular emphasis on the SECAs in the Baltic Sea and the North Sea/English Channel. Most of the gas-fuelled vessels in service are in Norway. The first vessel entered service in 2000 (by the end of 2013 the Norwegian fleet had increased to more than 30 vessels). The lead nations within the EU are Denmark and Sweden but other countries – including the Netherlands, Finland, Belgium, Germany and France – are also involved or have ordered vessels for their coastal or short-sea trades.

North America started later than Europe. However, the amount of recent activity means that this region looks set to overtake Europe very quickly – primarily in the USA, but also in Canada. No Already vessels are on order in the USA and in Canada with more set to follow.

In the **Far East**, Japan and China are both very active in putting systems in place to

enable LNG to be used as a marine fuel. However, it is South Korea that has built the first vessel. It is in service in Incheon harbor. China has two LNG-fuelled tugs in service with CNOOC, one of the Big Three national oil and gas companies, and has ordered many inland waterway vessels.

There is also interest being raised in the **rest of the world**. Probably the world's most advanced LNG-fuelled ship operates between Argentina and Uruguay (gas-fuelled, gas turbine-driven, high-speed ferry entered service in 2013). Brazil has a CNG ferry in operation.

Source: Society for Gas as a Marine Fuel (2014)

From its beginnings in Norway, the LNG-fuelled fleet has expanded and the order book is growing globally and across every ship segment. The latest trends in terms of fleet growth are highly encouraging with many firsts in recent years. New orders have been placed for Ro-Ro vessels, multi-purpose freighters, container ships and tugs as well as passenger ferries and offshore service vessels.^{xiv}

In February 2015, Harvey Gulf International Marine, LLC became the first North American owner/operator of a dual fuel offshore support vessel to bunker LNG as a marine fuel and the first to also successfully complete the first truck to vessel transfer of LNG when it bunkered the M/V Harvey Energy on LNG.

The US shipbuilder General Dynamics NASSCO launched the Isla Bella, the world's first container ship powered by LNG in April 2015. United Arab Shipping Co. is building 10 large container ships that can be adapted to run on LNG. MOL also is building ships that can be converted to LNG operation. The list of operators building LNG-ready ships includes Nordic Hamburg Shipping and U.S. domestic operators Matson and Crowley Maritime.

According to DNV GL, as of May 2015, there were 63 LNG-fueled vessels in operation worldwide (excluding LNG carriers and inland waterway vessels); and 76 LNG-fueled vessels on order. According to projections (DNV 2014) LNG-fueled vessel will soar from the approximately 140 of today to around 1,000 by 2020.

While many shipowners have not directly opted for LNG, they have chosen to make their newbuilds

“LNG-ready” in accordance to the new “International Code of Safety for Ships using Gases or other Low Flashpoint Fuels” or IGF Code.

Table 8: A History of LNG-Fuelled Vessels
The patriarch of LNG-fueled vessels is double-ended car/passenger ferry “Glutra” with a capacity of 300 passengers and 100 cars. It was built at Langsten Yard in Norway, and put in operation in February 2000.
The world’s first LNG-fueled PSV was the Norwegian-flagged “Viking Energy” put in service in April 2003; quickly followed by her sistership “Stril Pioner” in July.
The “KV Barentshav”, launched in 2009, was the first of three Norwegian LNG-fueled Patrol vessels.
The “Bit Viking “Oil/chemical tanker was the first ship to be converted from HFO to LNG in 2011.
Then came the first cargo vessel, the “Høydal”, in 2012.
The first LNG-fueled ship built in Asia was the “Econuri”, a pleasure craft from Incheon Port Authority, built by Samsung in 2013.
The “Viking Grace” was the first LNG-fueled large RoPax ferry. It was built at STX Europe Turku Shipyard in Finland, and took service on January 2013 on the route Stockholm–Turku.
Sister cruiseferries “Stavangerfjord” and “Bergensfjord” were built in July 2013 and April 2014 respectively.
The first LNG-fueled high speed RoPax, the “Francisco”, started operations in 2013 on the route Montevideo-Buenos Aires.
The first LNG-fueled tugs were the Chinese “Hai Yang Shi You 521” and “Hai Yang Shi You 522” operating in the Gaolan Port in Zhuhai, near Hong Kong since 2013. The Norwegian “Borgøy” and “Bokn” were delivered in 2014.
In 2015, Harvey Gulf of the US launched the “Harvey Energy”, the first LNG-fueled PSV outside Norway.
There are 14 LNG-fueled boxships on order. These are from Brodosplit (two) and GNS Shipping (four); as well as from TOTE, Crowley and Matson from the US (two each); and will be delivered between 2015 and 2018.
UECC has ordered two LNG-fueled car carriers.
DEME has placed an order for two dredgers and a cable layer to be LNG-fueled, with delivery in 2016.
There is also an order for an Icebreaker from the Finnish Transport Authority, and four Cruiseships from Carnival Lines.
UASC has ordered eleven 15,000 TEU and six 18,800 TEU LNG-ready containerships. And SEACOR has ordered three LNG-ready tankers.

Source: DNVGL. *Highlight Projects In The LNG As Fuel History.* / Ferreiro, J. (2015)

Ship owners with the highest level of preparedness (such as having a board committee overseeing environmental, social and governance risks, a strong fleet renewal program with targets, and a relatively low fleet average age) will be best positioned to comply with the new regulations to

reduce emissions (Sustainanalytics 2013).

Other industry players, such as engine manufacturers have already begun responding to the new regulations too.

Rolls-Royce, for whom ship engines represent approximately 4% of its total sales, predicts that regulations will stimulate the search for more efficient and technologically advanced engines^{xv}. In June 2012 the company sold its first gas-powered engines to Island Offshore.

MAN has also launched a new engine that can run on a mix of natural gas and diesel. Its ME-GI engines can help reduce SOx emissions by 95%.

Wärtsilä, through its Hamworthy Gas Systems division, is co-operating with Rolls-Royce to supply LNG engines for ships. In January 2013, Wärtsilä delivered a LNG-powered passenger ferry to Viking Line.

Mitsubishi plans to deliver a LNG-powered marine engine to Mitsui Engineering & Shipbuilding Co., Ltd.

In addition, Caterpillar Inc. is also focused on developing LNG for the marine industry.

Moreover, a number of funded research projects currently focus on LNG as ship fuel. These are:

- HELIOS – High-pressure Electronically Controlled Gas Injection for Marine Two-Stroke Diesel Engines, EU-Commission funded joint industry project
- CNSS – Clean North Sea Shipping, working a LNG bunker showcase, EU-Commission funded joint project
- TEN-T LNG Infrastructure – coordinated by the Danish Maritime Authority
- BUNGAS – LNG bunkering with a focus on technical aspects, German and Norwegian funded joint industry project
- GASPAX – ship design for using LNG as ship fuel, German funded joint industry project

Research by Lloyd's Register (2012) - considering the base case scenario model, with what is

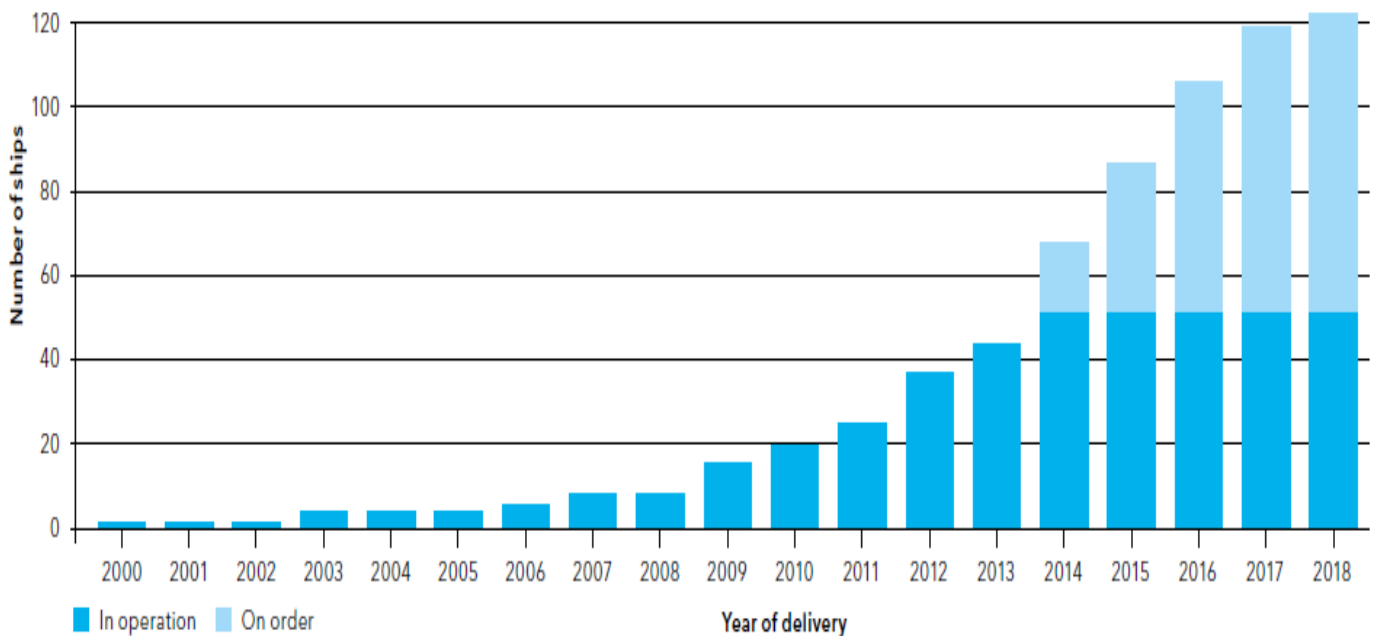
known today about the factors affecting adoption of LNG - forecasts 653 newbuilds will adopt LNG-fuelled engines by 2025 on deep sea routes. This represents 4.2% of global newbuilds forecast to be delivered during the period 2012-2025.

The high case scenario model output was much more favorable towards LNG-fuelled newbuilds when the forecast price of LNG bunker fuel was reduced by 25%.

The low case scenario model – with a higher forecast price of LNG bunker fuel and a later implementation date of global sulphur limits – generated demand for just 13 LNG-fuelled newbuilds for deep sea shipping up to 2025.

Interest in LNG powered ships can be negatively affected by the cost to produce them as they are 10 to 25 percent more expensive to build than vessels running on fuel oil. An average of five to eight years is needed to recover the higher costs, according to DNV GL. These are all important factors impacting on the decision to opt for LNG or not which is examined further below (Part 5.2), however, as Figure 3 shows (see below), the LNG fleet is still projected to grow.

Figure 3: Development of LNG-fuelled fleet



Source: DNVGL, 2014

In terms of state support for gas powered shipping, so far, only China and Europe have been showing such signs, and only in Europe has there been significant commercial uptake. There are projections that with the UK increasing the amount of LNG imports from Qatar and elsewhere it will be the next European country to build small scale LNG infrastructure, as might Spain (Lloyds List 2015).

Furthermore, China LNG has signed strategic co-operation agreements, valued at about \$754 million, with nine shipyards in China covering the financing, manufacturing and retrofitting of LNG-fuelled vessels, as well as the construction of LNG and 'clean diesel' bunker stations in the country. The deal includes LNG bunker facilities.

Additionally, in a state-backed deal, Chinese shipbuilder Honghua will build up to 200 gas-powered vessels to transport materials along inland waterways. These will be small vessels, of between 700 gt to 1,350 gt.

5.2 THE PACE OF CHANGE

Decisions to convert to LNG involve consideration of factors primarily involving (ABS 2014): a. Compliance with emissions regulations, and b. Economic and cost drivers, including fuel costs, repowering and new builds, availability, and cost of LNG.

Due to an absence of initiatives from Asian governments to request that their territorial waters be designated as ECAs, the pace of change will be slow and the solutions regional, at least until 2020.

According to Adamchack and Adede (2013), low natural gas prices in the U.S, and LNG prices below Brent crude oil price in Europe provides incentives to move to LNG while meeting the 0.1% sulphur limit effective in 2015. It is more difficult to make a strong economic argument in Asia Pacific as oil indexed LNG prices reduce the economic incentives.

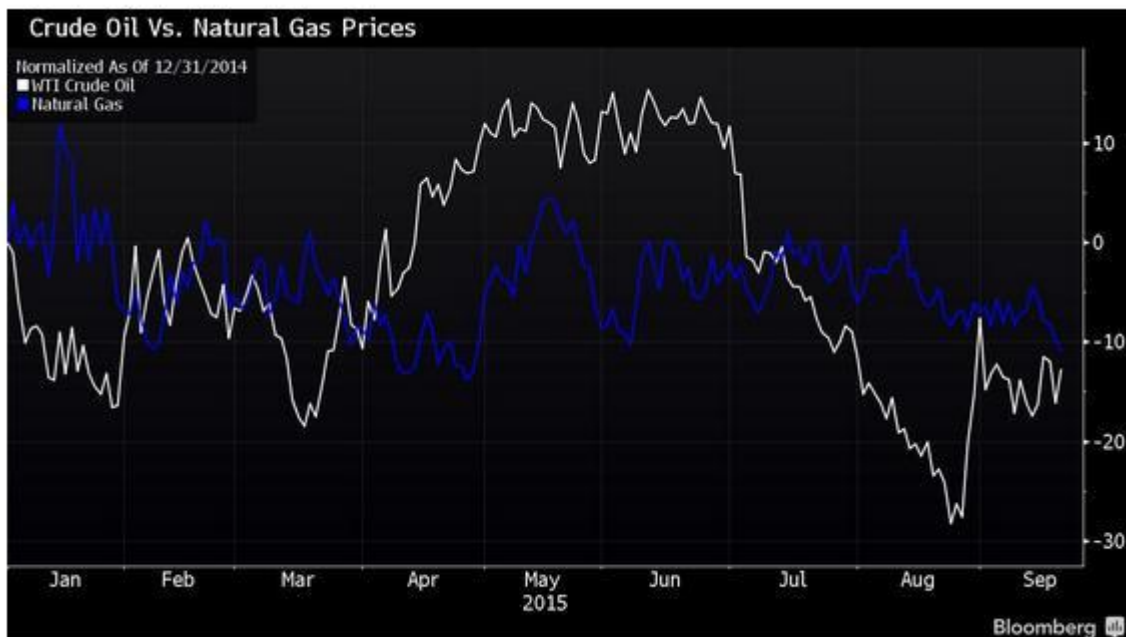
The global outlook will remain fog bound and no clear fuel choice will emerge (see Figure 3 below) as shipowners will opt for flexibility in their ship orders. Given the considerable uncertainty around both fuel price differentials and regulations, this strategy will prove key (Adamchack 2013).

According to Clarksons Research Services, the uptake of LNG as a fuel will additionally depend on

how bunkering infrastructure and technology develops (Parry-Jones, 2014). As this thesis has portrayed, great strides are already being made in this respect.

LNG prices are expected to trade in relatively narrow range (see Figure 4 below) as exports from the U.S. and Australia rise and global demand, pressured by China's slowing economy, remains sluggish according to a report by Bank of America (Bloomberg 2015).

Figure 4: Crude Oil Vs. Natural Gas Prices



Source: Bloomberg (2015)

Natural gas output in the U.S. rose to a record 2.455 trillion cubic feet in December, according to the Energy Information Administration (EIA)^{xvi}. Marketed production will expand 5.7 percent to 78.95 billion cubic feet a day in 2015, according to latest estimates. Other countries are also adding to the glut, such as Australia, which has two liquefaction projects to launch in 2015.

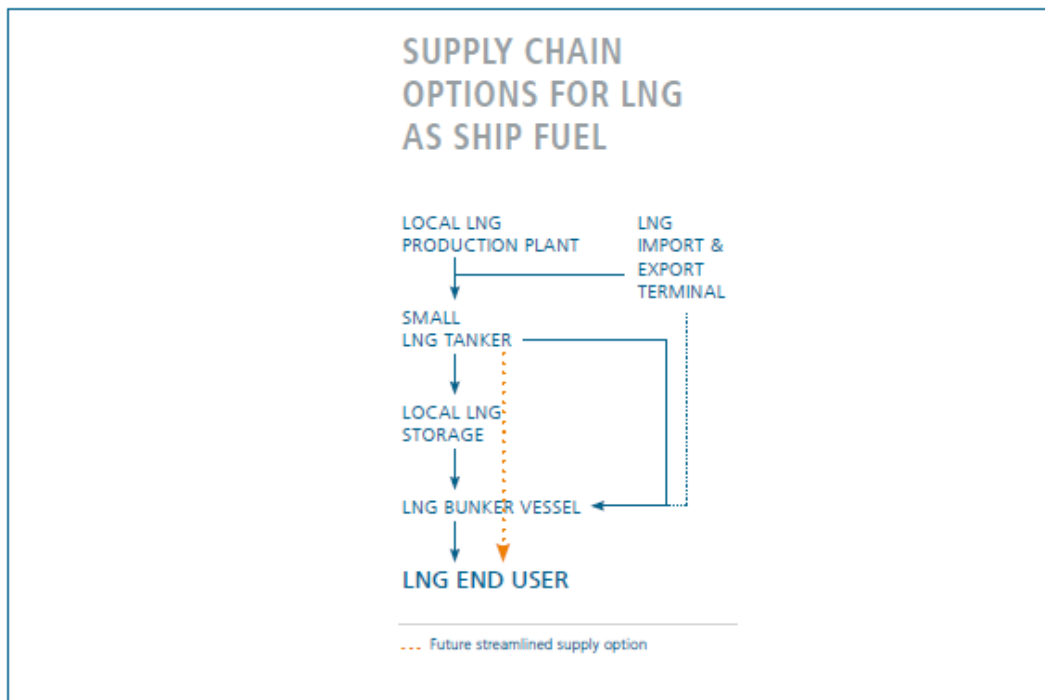
Diversity in shipping fuel is being increasingly explored. According to Poten & Partners (Bloomberg 2015), in the short - to mid - term LNG is likely to be available at competitive prices. While LNG contracts are historically linked to crude, adding supply mainly from the U.S. to the market is creating more choice for shipowners.

Despite the fact that a full – scale supply chain (Figure 5) for LNG as ship fuel is not yet available,

current developments point to much progress being made in this area as access to LNG bunkering is improving and all data shows that specific LNG ports will be feasible in the long – term.

Other viable options for the spread of LNG as bunker fuel include re-export from existing large-scale LNG terminals and LNG bunker vessels which are used for feeding the LNG supply chain.

Figure 5: Supply chain options for LNG as ship fuel



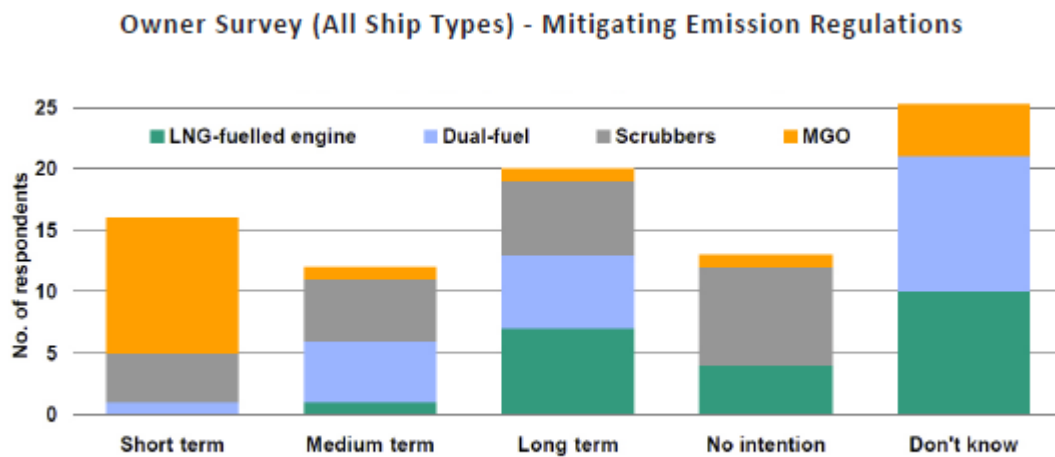
Source: Germanischer Lloyd (2013a)

Lloyd’s Register asked fourteen of the world’s leading shipping companies about their intention to implement technologies to mitigate non-GHG emissions (Lloyds Register 2012). The results point to four types of solutions as the most relevant to comply with upcoming non-GHG related regulations. The first two solutions consist of using low-sulphur marine gas oil (MGO), more commonly called low-sulphur fuel, and a fuel mix (dual-fuel) usually made of natural gas and diesel. The third solution is the use of scrubbers and the fourth involves the use of liquefied natural gas (LNG). Low-sulphur fuel is currently considered the best short-term solution for mitigation, with scrubbers being a solution in the medium term, and dual-fuel/ LNG being considered longer-term solutions.

Figure 6 (below) clearly shows that shipowners consider LNG-fuelled engines to be a long-term

solution to emission standards regulation.

Figure 6: Owner Survey (All Ship Types) – Mitigating Emission Regulations



Source: Lloyds Register (2012) LNG-fuelled deep sea shipping: The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025.

From the survey of shipowners on deep sea trades (Lloyds Register, 2012), the following conclusions are drawn:

- Low-sulphur fuel oil is seen as a short-term option for compliance with SO_x emission regulations.
- Abatement technologies are seen as a medium term option.
- LNG-fuelled engines are a viable option in the long term, particularly for ships on liner trades.

Using the LNG bunker demand model, Lloyd's Register has developed and examined scenarios based on assumptions for:

- wider implementation of ECAs
- the date of the strict global sulphur limit implementation
- the propensity of shipowners to adopt LNG as a fuel for newbuilds
- bunker fuel oil and LNG bunker price forecasts

In the Base Case Scenario current ECAs and a 0.5% global sulphur limit in bunker fuel are implemented from 2020:

- 653 LNG-fuelled newbuilds forecasted for the period up to 2025 (4.2% of global deliveries from 2012 to 2025)
- LNG bunker demand is expected to reach 24 million tonnes (MnT) by 2025 for deep sea trades (1.5% of global LNG production and 3.2% of global HFO bunker consumption).

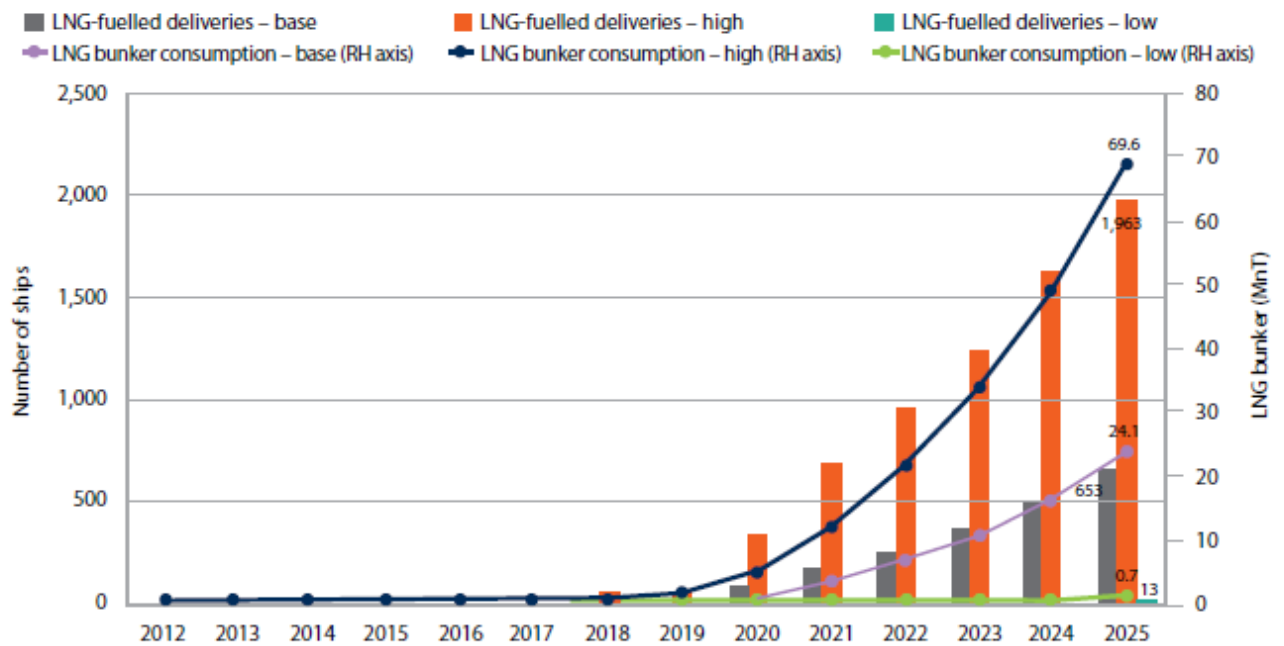
In the High Case Scenario a 25% decrease on the forecast LNG bunker prices is used and a 75% increase in propensity for newbuilds to convert to LNG-fuelled designs from 2020-2025:

- 1,963 LNG-fuelled newbuilds forecasted for the period up to 2025 (12.6% of global deliveries from 2012 to 2025)
- LNG bunker demand is expected to reach 66 MnT by 2025 for deep sea trades (4.2% of global LNG production and 8.0% of global HFO bunker consumption).

In the Low Case Scenario a 25% increase in forecast LNG bunker prices is used and implementation of global sulphur limits shifting to 2023. Sensitivity testing indicates that shifting implementation to 2025 for the low case would generate a zero demand for LNG-fuelled newbuilds:

- 13 LNG-fuelled newbuilds forecasted for the period up to 2025 (0.1% of global deliveries from 2012 to 2025)
- LNG bunker demand is expected to reach 0.7 MnT by 2025 for deep sea trades (0.001% of global LNG production and 0.002% of global HFO bunker consumption).

Figure 7: Cumulative global LNG fuelled newbuilds and LNG bunker consumption (base, high and low cases)



Source: LNG-fuelled deep sea shipping: The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025 (August 2012) - Lloyd's Register

5.3 ECONOMIC & ENVIRONMENTAL FACTORS

The cost benefits for shipowners of adopting LNG as a marine fuel have lately been ‘partially eclipsed’ by the low crude oil prices despite LNG’s greener credentials. However, from the ship owners’ perspective, success in the industry is more often than not dependant on how well one can predict future developments. Issues such as regulations and rules, safety and public perception, ship types, technology, performance and the environment must all be factored in and co-examined with economic factors (such as fuel price comparison) in order for the decisions that will shape the future of the industry to be made today.

When the price of crude goes up, what will happen with the price of gas in terms of what is going to happen? The answer to such questions is usually the result of instinct as well as an informed decision. Making an early move has also proven key for many ship owners throughout maritime history. Combining research, experience and detailed analysis of a complicated global market is the challenge facing industry players when it comes to embracing newbuilding opportunities, building LNG bunkering into designs and expanding the infrastructure and technology already available

more widely.

Having said that, natural gas has generally been cheaper than prevalent bunker fuels, and this has not changed despite the recent collapse of oil price. In terms of British thermal units, the benchmark Henry Hub gas price was 13.5% lower than that of heavy fuel oil and almost half the price of 0.1% sulphur marine gasoil as of mid-March 2015 (Lloyds List 2015b).

LNG offers the best economics to shipowners and the best environmental benefits to the public, according to a report by ship classification society Det Norsk Veritas (DNV 2011). Furthermore, with increasing output after the shale revolution, gas supply is expected to be abundant and LNG is the only clean fuel which is available worldwide on a large scale to meet the needs of worldwide shipping for the foreseeable future (Lloyds List 2015b).

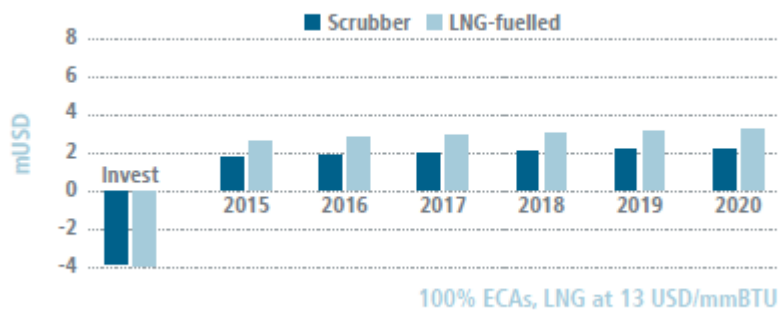
There are essentially two types of LNG trading. Firstly, there is the international bulk trade, in which LNG moves from one country to another, often over very long distances, in large LNG carriers. Secondly, there are the smaller local producers that produce LNG for local markets. The price of LNG will depend on which of these models is used and where in the world it is sourced from.

Comparing the economics of LNG bunker with oil is difficult, because they depend on the precise compositions of the LNG and the oil. They also depend on engine type and efficiency. However, over the long term, LNG delivered to a ship as fuel is expected to cost less than MDO and to be generally comparable with HFO (Society for Gas as a Marine Fuel, 2014).

Switching to a low sulphur fuel oil as an alternative option may require minimal, if any, additional capital costs in the short-term, however, the long-term economics make it less attractive. Low sulphur fuel oil is higher priced when compared with alternatives and availability is not guaranteed (Hart, 2015). In addition, owners moving forward with the use of low sulphur fuel oil will eventually still have to install air quality control equipment, or scrubbers, in order to meet Tier III limits for nitrogen oxide (NO_x).

Owners could continue using high sulphur fuel by adding scrubber technology to their existing fleets. The challenge with this option is that there is waste generated in the scrubber systems and disposal facilities will add more operational costs to the high fuel and capital requirements (Hart, 2015). Furthermore, evidence shows that in the long term it is a costlier option (see Figure 8 below).

Figure 8: Annual cost advantage for a 1,250 TEU container vessel compared to standard vessel using standard fuel



Source: Germanischer Lloyd (2013a)

According to ABS (2014), operators considering the option of installing new machinery (or converting existing machinery where possible) designed to operate on an inherently low sulphur alternative fuel are seeing the LNG economic factors in the U.S. move in a favorable direction.

Today, shale gas accounts for a significant portion of U.S. natural gas production. Up from near zero in 2000, it is predicted to account for about half of U.S. gas output by 2040.³ A significant effect of the fracking^{xvii} revolution has been in LNG.

According to the ICS (2014), the consensus of opinion within the global industry is that it will be possible for shipping to reduce CO₂ emitted per tonne of cargo transported one kilometre (tonne/km) by 20% between 2005 and 2020, through a combination of technological and operational developments, as well as the introduction of new and bigger ships, designed to the new IMO Energy Efficiency Design Index.

In the longer term, depending on technological developments which at the moment cannot be fully anticipated, the industry believes it should be possible to deliver even more dramatic emissions reductions (ICS 2014).

Shipping companies have a very strong incentive to reduce their fuel consumption and thus reduce

their CO₂ emissions: bunker costs represent an increasingly significant proportion of ships' operational expenses, having increased by about 400% since 2000 (ICS 2014).

There is every expectation that marine bunker prices will remain high. Furthermore, the cost of ships' fuel is expected to increase by a further 50% as a result of the increased use of (low sulphur) distillate fuel that will follow the implementation of the new IMO rules (MARPOL Annex VI) that apply in Emission Control Areas in 2015 and globally from 2020 (ICS 2014).

LNG has about 60 percent of the Btu value of an equivalent volume of marine diesel, so it takes 1.7 gallons of LNG to produce the same power as one gallon of diesel. However, the lower cost of LNG combined with lower emissions gives LNG an advantage in operating costs. Various studies have put that advantage at anywhere from 15 to 30 percent or more, depending on the price differential between the two fuels.

In terms of investment costs, the added investment cost of choosing LNG fuel for new ships is expected to decrease in the future. By how much and how soon is largely dependent on the number of LNG-fuelled ships being contracted (DNV 2011).

One of the main cost drivers is the storage tank for natural gas, as pressurized or insulated tanks are generally more expensive than diesel oil tanks. The standard LNG storage tanks currently used are spherical and insulated. These occupy more space than traditional bunker tanks. LNG storage requires additional space since natural gas takes up roughly twice the space occupied by diesel oil and various safety constraints also have to be fulfilled. An emerging option is retrofitting vessels to run on LNG. By modifying the engine, auxiliary machinery, piping networks, and tank configuration, existing vessels can be adapted to use LNG (DNV 2010).

LNG investment costs will also vary significantly between ship types and must be assessed from case to case. Investment cost for retrofitting LNG machinery will vary even more between ship types, but experience indicates that it can be profitable even without ECA requirements.

In terms of fuel costs, a Germanischer Lloyd (2011) study shows that with 65% ECA exposure, an LNG system payback time under two years is predicted for the smaller container vessel sizes (using the standard fuel price scenario). For the 2,500 TEU vessel, a comparison of payback times for the scrubber and for the LNG system, and varying LNG prices, shows that the LNG system is attractive

as long as LNG (delivered to the ship) is as expensive as or cheaper than HFO when the fuels are compared on their energy content.

For larger container vessels typically operating at smaller ECA shares, for instance the 14,000 TEU vessel, the LNG system has the shortest payback time (using the standard fuel price scenario), and the use of a WHR system further reduces the payback time. The price of LNG delivered to the ship is difficult to predict. Base LNG prices vary from the USA to Japan by a factor of four. European base LNG prices appear attractive at around 10 USD/ mmBTU, even with small-scale distribution costs added. An LNG price of up to 15 USD/mmBTU could give LNG systems a competitive advantage against scrubbers in terms of payback for the smaller vessels considered in this study.

Small-scale LNG distribution is just starting to become available in Europe (outside Norway) and it remains to be seen which LNG-fuel price levels will be established.

Alternatives, such as switching from bunker fuel to a fuel that contains a much lower percentage of sulphur can be expensive. As of September 12, 2014, the price of 0.1% sulphur marine distillate was about \$293 per tonne higher than the price of bunker fuel, or 48% more expensive (Fung, et al, 2014).

An analysis of engineering and operational costs, conducted as part of the North American ECA proposal (IMO 2009), found that:

- The price of a new vessel equipped with fuel switching equipment and other modifications for using low-sulphur fuel (such as an extra fuel tank for distillate) would increase by 0.5% to 2%, depending on the vessel type.
- The operating cost increase would vary, depending on route and time spent in an ECA. The cost of operating a vessel servicing Singapore, Seattle, and Los Angeles/Long Beach, which includes about 1,700 nm of operation in waterways covered by the ECA, would increase by about 3%.
- The total costs would represent an US\$18 increase in the shipping cost per container for a container ship. For a seven-day cruise on a vessel operating entirely within the ECA, the price per passenger would increase by about US\$7 per day.

Converting to LNG has two major cost components:

a) the cost of the infrastructure to fuel the vessels and b) the cost to replace or convert current vessels to LNG. In both cases, financing interest from investors is strong and will move projects forward (Hart, 2015).

“Financing for fueling infrastructure will likely come from two sources: either end users will invest and own/operate the refueling infrastructure themselves or the liquefaction will be done in a quasi-merchant plant model. In the latter case, a third-party invests the upfront capital and then sells the LNG to end users. Guaranteeing the off-take for quasi-merchant plants will be the largest risk for plant operators and end users in most regions of North America, because there is adequate pipeline capacity available to supply fueling stations. However, in the Northeastern United States, pipeline capacity constraint will be the largest obstacle for investors because the region’s lack of available capacity becomes more of an issue for investors.

Financing the conversion of fleets is another area of opportunity/innovation. Third-party companies, such as energy investors, are interested in providing the upfront capital to convert or replace engines with LNG power plants. The owner of the vessels will then share the fuel savings realized for a designated payback period” (Hart, 2015).

By adding an extra 0.5%-1% to a ship's price, owners can optimize vessel design to leave room for future retrofitting that enables ships to fuel on LNG once supply is readily available (Lloyds List 2015b).

In terms of **environmental factors** – which heavily come into play as a result of the changing emissions regulation explored in Part Two - compared to HFO, LNG first and foremost greatly reduces emissions to air.

In terms of NOX emissions, the four-stroke and two-stroke low pressure engines reduce these emissions by 85% compared to HFO. While the high pressure two-stroke engines still reduce NOX by 40% without exhaust gas treatment. Particle emissions are reduced by 95% and more. Because

LNG does not contain sulphur, these emissions are eliminated completely. All emissions to the atmosphere relevant for human health and the so-called “black carbon” effect on global warming are reduced significantly by burning natural gas instead of HFO or MGO. As explained below, the effect on CO₂ emissions is also positive (DNVGL, 2014).

DNV GL (DNVGL, 2014) evaluated the greenhouse gas emissions from production to the tank of the ship (Well To Tank; WTT) and the emissions from the combustion of the fuel (Tank To Propeller; TTP) in two studies in 2012. Methane has a much higher greenhouse warming potential than CO₂. The Kyoto protocol gives Methane a value that is 21 times the global warming potential (GWP) of CO₂. This means that an unburned methane molecule has 21 times the GWP of one molecule of CO₂.

A comparison of emissions from different fuels indicates that the WTT emissions for HFO, MGO and LNG are similar and small compared to the TTP emissions. For LNG, the methane slip has been considered for WTT and TTP. In the engine process, methane is mainly released as blow-by of the cylinders into the crankcase, valve overlapping effects and from incomplete combustion.

The DNV GL study (DNVGL, 2014) assumed the methane slip for four-stroke engines at 1.5% of the fuel. Taking this into account, the GWP is still reduced by 8 to 12%, as can be seen in Table 2. The greatest reduction in greenhouse emissions is reached by the high pressure engines, which reduce the CO₂ effect by 26% compared to HFO.

5.4 FUEL SHIFTS CAN HAPPEN FAST

Maritime history shows that the shipping industry is quick to adapt to new fuels, if the right incentives are in place. For example, in the period between 1914 and 1922, the percentage of vessels using oil rather than coal in their boilers increased from three per cent to 24 per cent. While the speed of this shift was abetted by the fact that owners could use existing machinery with minimal modifications, it shows that the industry can move quickly if a better solution is available. However, history also shows that fuels that demand new types of machinery, such as the transition from coal to oil via the combustion engine, slows the migration to new energy sources (DNV GL, 2014: pg.34).

High efficiency and low fuel consumption generally means fewer emissions. However, it is becoming increasingly evident that LNG will only become competitive and therefore commercially

feasible, if it can be offered below the HFO price, or if the 0.5% S regulations come into force in 2020^{xviii}.

Shipowners are keen to ensure that new vessels must not only be the most competitive when put into service compared to conventional ships but, moreover, the most competitive in the years to come, while complying with the increasing environmental demands of IMO MARPOL VI regarding emissions of SOX, NOX, diesel particles, and CO₂. These concerns will become all the more pressing should ECAs be extended.

LNG as a fuel appears commercially the most attractive when comparing the expected prices from 2020 of low sulphur heavy fuel oil (LSHFO) or Marine Gas Oil (MGO), and the extensive long term availability of natural gas. For Europe, DNV GL compared similar prices between LNG and HFO until 2020, but from 2020 onwards (if not delayed until 2025) attractive LNG prices will be compared with those for higher cost distillates or blends. According to DNV GL^{xix}, the still sizeable investment costs for LNG retrofit will achieve very fast pay-back times once the fuel price differences become visible.

Eventually, there will be an LNG bunkering procedure that follows the same pattern as that of heavy fuel oil – customers will expect a similarly convenient bunkering, including an acceptable time frame and guarantees for the safety of crew and passengers.

It is the upcoming challenge to develop an LNG bunkering system that covers all organizational, safety and technical aspects and requirements.

Use of LNG as bunker fuel for ships represents a real alternative to conventional marine bunker fuel oils when considering compliance with more stringent sulphur limits because of its virtually 0% SO_x content in emissions (depending on engine type).

A comparison of the three main options for compliance with strict sulphur limits (see Table 9 below) proves LNG is the best suited to tackle the pressing environmental issues but still has a long way to cover before it displaces conventional marine bunker fuel oils.

Table 9: The three main options for compliance and corresponding emission reductions

Compliance option	LNG	HFO	MDO/MGO
CO2 removal	10-20%	Abatement technologies	No
SOx removal	100%		MDO: <2%; MGO: 0.01 – 1%
NOx removal	Up to 80-90%		Abatement technologies
Particulate matter	98-100%		
Regulation in place	Developing	Yes	Yes
Infrastructure	Early stages	Yes	Yes
Cultural factors	Higher	Established	Established
Cost of use	LNG storage tank size; LNG fuel price uncertain; possible loss of cargo space	Abatement technologies required	
Potential to stretch the technology	Further CO2 reduction	End of cycle	
Challenges / differences	Bunker space/cryogenics / possible methane slips	Abatement technologies Varied blends of distillates 2020	

Source: LNG-fuelled deep sea shipping: The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025 (August 2012) - Lloyd's Register

Issues that need to be dealt with effectively are related to pragmatic decisions for navigation in ECA only zones or globally, endurance, suitable LNG tank size, tank construction type and costs, the location of the tank in the ship and economy of retro-fitting and the selection of fuel gas supply system as well as the position of bunker stations and the vent mast for the least loss of precious container stowage space. The further development of efficient bunkering logistics along the trading routes with the availability of adequate LNG bunker quantities and refueling without lost idle time is a further demand^{xx}.

“The initial focus for LNG conversions will be containerships and bulk carriers – vessels that spend the most time in ECA-restricted areas. However, any vessel that spends 30 percent or more of its time within an ECA-restricted area will benefit from a switch to LNG. Today, this criteria represents approximately 10,000 ships, a number that is expected to increase by 10 to 15 percent by 2020.

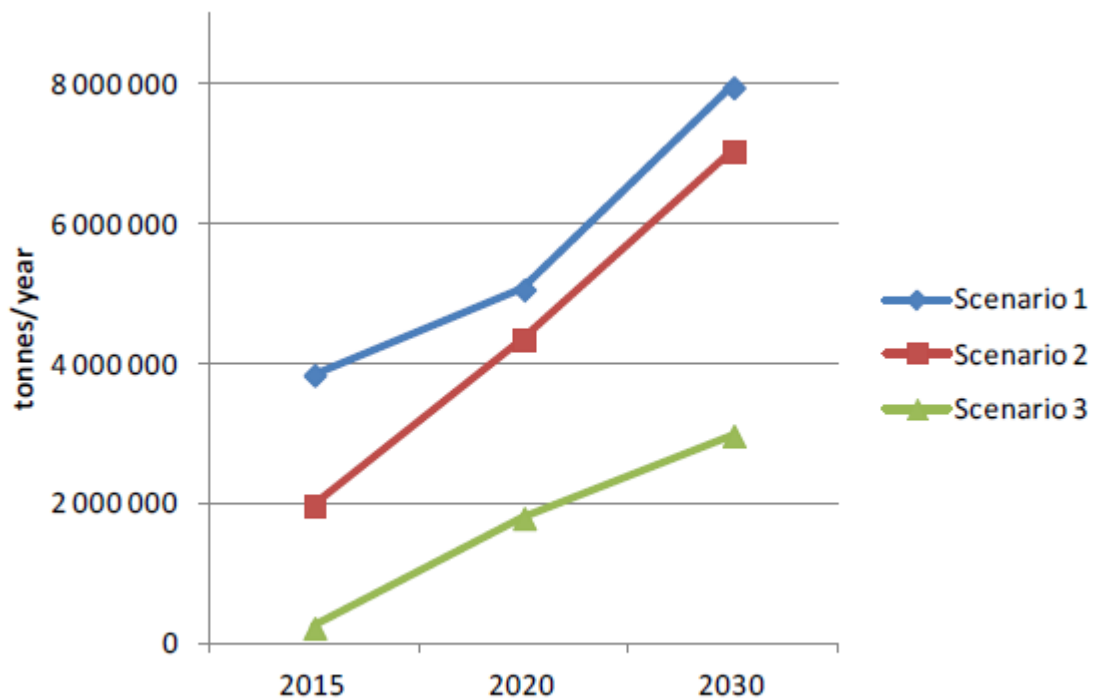
As ECA regulations take effect in North America, the need for a reliable source of LNG to marine vessel owners will drive infrastructure development. Vessel

owners/operators know the impacts expected in the market over the next five years and will soon have to make key decisions for the near term and long term”(Hart, 2015).

From a shipowner’s point of view, the choice to switch to LNG will be based on the relative future prices of the different fuels and their view of the life of their investment. According to a study by the Danish Maritime Authority (2012), using MGO is the compliance strategy with the lowest investment cost, and the highest operational cost.

For new-buildings, the analysis in most cases shows payback times for the LNG compliance strategy of around 2 years – slightly less with low LNG prices and up to four years with higher LNG prices. The HFO and scrubber strategy has generally slightly shorter payback times than any of the LNG options. With high LNG prices the difference between the different compliance alternatives is more marked. Retrofitting has slightly longer payback times, however still within range of 2 - 4 years.

Figure 9: Scenarios of LNG demand with MGO prices at the central level



Scenario 1 – low level LNG price, Scenario 2 – central level LNG price and Scenario 3 – high level LNG price.

Source: Danish Maritime Authority (2012)

According to a study by the Danish Maritime Authority (2012), LNG is a viable compliance strategy from shipowners' point of view, with short pay-back times (compared to MGO). One key issue for the demand analysis is of course the LNG price development. The price of LNG depends on the cost of supplying the LNG according to the findings of the report.

To summarize, as mentioned by leading shipping industry news source Lloyds List (2015):

There is a line of thinking that believes ordering gas powered ships now for delivery when prices are more competitive is a good idea. Yet it will not happen in huge numbers as owners remain wary of infrastructure shortcomings and relative fuel prices along with the additional newbuilding costs.

LNG fuel for shipping is only going to be a global phenomenon once there is commercial gas demand ashore and a global bunkering network. To do that there needs to be a significant price change with oil and coal so that gas becomes a more dominant energy source, but that tipping point varies between regions just as the cost of natural gas prices varies.

CONCLUSION

The main hypothesis of this dissertation has been the changing environment of the maritime fuels market as a result of meeting new legislation limiting sulphur emissions from ships.

I have provided an overview of the issue of reducing shipping emissions (Part One) as well highlighted why this is important and how it is being brought about, firstly in North America and northern Europe (Part Two).

This dissertation has presented the latest regulations for emissions control in place in order to indicate what requirements need to be met and how controls and sanctions are affecting the industry. Implications for shipping were particularly highlighted (in terms of infrastructure, economic effects, etc.) in Part Three.

In the Fourth Part of my thesis, LNG bunkering was presented in detail (procedures, regulations, safety) in order to understand the specifics of using LNG as a fuel for shipping and assess advantages and concerns for industry players.

In the final part (Part Five) research was presented into the development of the LNG-powered fleet along with an assessment of the economic factors determining the role of LNG in the marine fuels market and the pace at which change is occurring.

This dissertation, through secondary research - the review and presentation of latest literature on developments on the subject examined – has shown that LNG fuelled vessels are a viable option for deep sea trades. A rising number of vessels globally are expected to adopt LNG-fuelled engines by 2018 through to 2025 (4.2% of global newbuilds forecast to be delivered by 2025).

Change has so far been incremental with LNG bunker and LNG-fuelled newbuild demand stretching away from the smaller scale (i.e. Ro-Ro passenger vessels, offshore service vessels, tugs, etc) to the larger (such as containerships, tankers, etc). Petroleum tankers and dry bulk carriers, mainly in the tramp trade, have proven more reluctant to adopt LNG as fuel thus far (Lloyds List 2015b). However, the motivation to consider using gas as ship fuel has become stronger. Three reasons are identified: (i) facilitating reduced SO_x emissions; (ii) reducing CO₂-emissions; (iii) attractive price.

As illustrated by this dissertation, energy has become the main cost-driver in shipping. While shipping is a carbon efficient transport mode, given that roughly 90% of the world trade is carried by ships, the negative impact of shipping on the natural environment (and human health) is significant. The industry considers LNG-fuelled ships to be the future in deep sea and short sea shipping.

Increasing limitations on the use of conventional fuel and rising fuel prices demand new solutions for marine transport. Undoubtedly, as shown in this thesis, the shipping industry is entering an era in which it is increasingly called upon to determinedly address a pressing environmental issue with huge business implications for shipping.

Looking to the future, oil is simply too valuable and limited a commodity for the world to continue to consume as a fuel; increasing the use of LNG preserves the world's resources to use in value-adding products such as plastics, coatings and consumer goods. The importance in the reductions in local air pollution that can be achieved through switching (cutting NOX 80%, almost eliminating SOX and particulate matter, and reducing CO2) also cannot be understated.

Is LNG bunkering the most effective solution to emissions standards regulation?

This dissertation has shown that efficiency is certainly assured when it comes to using LNG as fuel in shipping and increasingly stricter emission standards regulation has served to facilitate the promotion of this option.

There are four aspects that, taken together, make LNG as ship fuel one of the most promising new technologies in this respect:

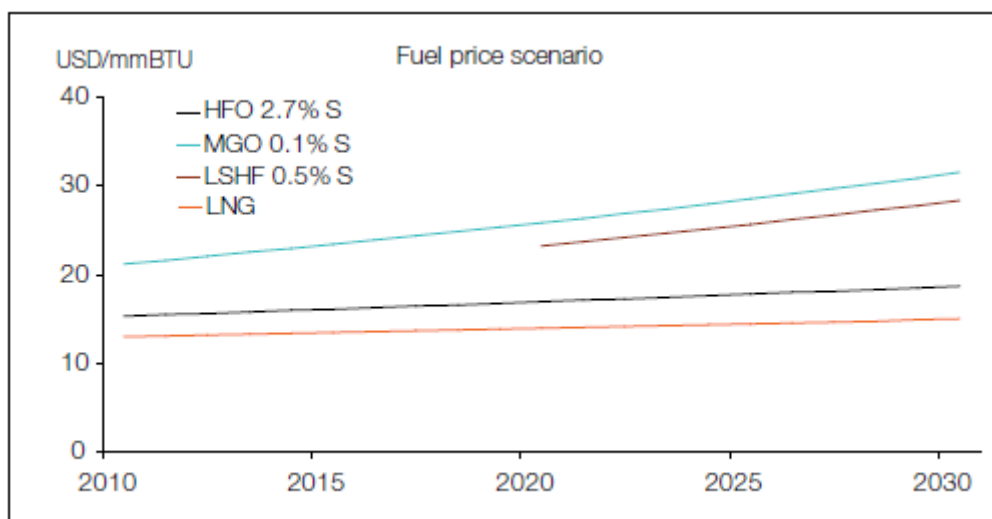
1. Using LNG as ship fuel can reduce sulphur oxide (SOx) emissions, which are created using fuel with a high sulphur content, by approximately 90% to 95%. This reduction is mandatory within the so called Emission Control Areas from 2015 on. A similar reduction will be enforced for worldwide shipping from 2020 on, pending a review at IMO which may move the introduction to 2025.
2. Reduction of nitrogen oxide (NOx) emissions down to IMO Tier III limits, applicable in ECAs from 2016, is possible for pure gas engines and four-stroke dual fuel engines which are typically

used onboard ships engaged in short sea and coastal shipping.

3. Due to the lower carbon content of LNG, a 20% to 25% reduction of carbon dioxide (CO₂) emissions is possible. The actual reduction depends on engine type and possible measures to reduce the partial slip of unused methane.

4. The current LNG price in Europe and the USA suggests that LNG could be offered at a price comparable to heavy fuel oil (HFO). This means that LNG will certainly look commercially attractive against the low-sulphur marine gas oil (MGO) within the ECAs. Current low LNG prices in Europe and the USA suggest that a price – based on energy content – comparable to heavy fuel oil (HFO) seems possible, even when taking into account the small scale distribution of the LNG.

Figure 10: Expected fuel prices



Source: Germanischer Lloyd (2011)

However, the uptake of LNG as a fuel will depend on how bunkering infrastructure and technology develops. LNG pricing and its comparative price difference with competing fuels will factor in heavily. So far, LNG has been used in niche sector vessels instead of deep sea carriers, proof that shipowners are not convinced LNG-fuelled ships will become the norm imminently.

It appears that the majority of ships will meet the 2015 SO_x ECA limits by switching to MGO in the short-term (Parry-Jones 2014). A relatively small proportion of the fleet and orderbook is reported to currently have scrubbers installed^{xxi} and these ships typically spend a lot of time in ECAs where SO_x limits are most stringent. However, when the global SO_x limit drops to 0.5% cheaper long-

term alternatives to MGO could be more attractive and scrubber systems may begin to be more popular.

While many shipowners have not yet directly chosen LNG as their fuel or preference, they have chosen to make their vessels “LNG-ready” in accordance to the IGF Code.

The shipping industry is increasingly coming to terms with the fact that collaborative action is necessary in order for pressing environmental issues to be addressed especially as shipping activities are projected to increase.

Warming effects of CO₂ and black carbon emissions from ships are expected to grow. Shipping is among the top emitters of Sulphur oxides (SO_x) and it also accounts for a significant portion of the world’s Nitrogen oxides (NO_x) emissions. As this dissertation has shown, the comparatively high emissions of sulphur oxides by shipping are the consequence of its being fuelled by heavy oil.

Having said that, there is no single solution to reducing emissions. As I have explained, both economic and regulatory factors are supporting an LNG-fuelled future.

Shipowners are keen to ensure that new vessels must not only be the most competitive when put into service compared to conventional ships but, moreover, the most competitive in the years to come, while complying with the increasing environmental demands of IMO MARPOL VI regarding emissions of SO_x, NO_x, diesel particles, and CO₂. These concerns will become all the more pressing should ECAs be extended.

Regulation such as the IMO’s stricter emissions requirements in ECAs which have come into force will directly affect about 40% of the world fleet in various ways.

Demand for LNG bunkering infrastructure at ports will only fully materialize if adequate supply exists, conversely the supply will only materialize if developers of the supply infrastructure are sure that the demand will materialize.

As shown in previous parts of this thesis, there are various types of **LNG facilities** already available and potential for further expansion. With more shale and natural gas being available, better access to LNG globally together with more competition, the **price** will remain low for foreseeable future.

According to some predictions, **demand for LNG bunker fuel** would increase by 25 million tonnes if 10% of the world's shipping fleet were to adopt LNG fuel by 2025.

Europe and the US are among the keenest to discuss LNG bunkering.

When it comes to using gas as a fuel, to ensure a **competitive fuel supply**, LNG bunkering must be possible for each type of gas-fuelled vessel under the same conditions as bunkering HFO.

The supply chain for LNG as ship fuel and bunkering remain issues that are currently being thoroughly researched and documented.

Reliable and safe concepts, established legislation, the regulatory framework and necessary competences, knowledge and skills are the main **requirements to develop a LNG bunkering infrastructure** – provided LNG is available, access to capital is given and the public is informed.

LNG as a shipping fuel is regarded as one of the most promising options to meet the new regulatory requirements as it has virtually no sulphur content. LNG is also priced lower than global bunker fuel and in many cases does not require the installation of additional process technology. Also, the safety record of LNG carriers is extremely good.

Moving ahead on LNG technology requires not just the support of the shipping industry but also the support of political decision-makers.

According to DNV GL, as of May 2015, there were 63 LNG-fueled vessels in operation worldwide (excluding LNG carriers and inland waterway vessels); and 76 LNG-fueled vessels on order. According to **projections** LNG-fueled vessel will soar from the approximately 140 of today to around 1,000 by 2020.

Research by Lloyd's Register (2012) - considering the base case scenario model, with what we know today about the factors affecting adoption of LNG - forecasts 653 newbuilds will adopt LNG-fuelled engines by 2025 on deep sea routes. This represents 4.2% of global newbuilds forecast to be delivered during the period 2012-2025.

However, interest in LNG powered ships can be negatively affected by the cost to produce them as they are 10 to 25 percent more expensive to build than vessels running on fuel oil.

As argued in previous parts of this dissertation, decisions to convert to LNG involve consideration of factors primarily involving: a. Compliance with emissions regulations, and b. Economic and cost drivers, including fuel costs, repowering and new builds, availability, and cost of LNG.

The latest literature on the subject suggests that the global outlook will remain fog bound and no clear fuel choice will emerge as shipowners will opt for flexibility in their ship orders.

The uptake of LNG as a fuel will additionally depend on how bunkering infrastructure and technology develops. As we have portrayed, great strides are already being made in this respect.

In the short - to mid - term LNG is likely to be available at competitive prices. While LNG contracts are historically linked to crude, adding supply mainly from the U.S. to the market is creating more choice for shipowners.

Despite the fact that a full – scale supply chain for LNG as ship fuel is not yet available, current developments point to much progress being made in this area as access to LNG bunkering is improving and all data shows that specific LNG ports will be feasible in the long – term.

Low-sulphur fuel is currently considered the best **short-term solution** for mitigation, with scrubbers being a solution in the **medium term**, and dual-fuel/ LNG being considered **longer-term** solutions.

LNG offers the best economics to shipowners and the best environmental benefits to the public. Furthermore, with increasing output after the shale revolution, gas supply is expected to be abundant and LNG is the only clean fuel which is available worldwide on a large scale to meet the needs of worldwide shipping for the foreseeable future.

Switching to a low sulphur fuel oil as an alternative option may require minimal, if any, additional capital costs in the short-term, however, the long-term economics make it less attractive.

The lower cost of LNG combined with lower emissions gives LNG an advantage in operating costs.

In terms of investment costs, the added investment cost of choosing LNG fuel for new ships is expected to decrease in the future. Investment cost for retrofitting LNG machinery will vary even more between ship types, but experience indicates that it can be profitable even without ECA requirements.

The example this dissertation focused on shows that for larger container vessels typically operating at smaller ECA shares, for instance the 14,000 TEU vessel, the LNG system has the shortest payback time.

Ultimately, LNG will become competitive and therefore commercially feasible, if it can be offered below the HFO price, or if the 0.5% S regulations come into force in 2020.

In terms of **concerns** being raised, the most notable issue is the heavy investment required in ship propulsion & fuel handling systems as well as investment in bunkering facilities that is needed. The development of new international safety regulations will also be required should LNG bunkering take off while availability is also an issue that needs to be addressed.

Furthermore, competition between ship owners will be massively distorted if lack of enforcement allows some in the industry to avoid meeting the new requirements, according to BIMCO.

In addition, limited availability of satellite terminals and bunker barges (floating refuelling stations for LNG) will make it difficult for most ships to switch from traditional liquid fuel to LNG.

Finally, compared to other fuels, the combustion of LNG emits significant amounts of another GHG: methane (CH₄) which has a high global warming potential; and the price of an HFO bunker can be found on the internet for most major ports while such openness is not present for LNG as a fuel or for LNG in small quantities.

(20.174 words)

Appendix 1

Annex VI *Regulations for the Prevention of Air Pollution from Ships* establishes certain sulphur oxide (SO_x) Emission Control Areas with more stringent controls on sulphur emissions and nitrogen oxides (NO_x) Emission Control Areas for Tier III NO_x emission standards.

Special areas under MARPOL are as follows:

Adoption, entry into force & date of taking effect of Special Areas			
Special Areas	Adopted #	Date of Entry into Force	In Effect From
Annex I: Oil			
Mediterranean Sea	2 Nov 1973	2 Oct 1983	2 Oct 1983
Baltic Sea	2 Nov 1973	2 Oct 1983	2 Oct 1983
Black Sea	2 Nov 1973	2 Oct 1983	2 Oct 1983
Red Sea	2 Nov 1973	2 Oct 1983	*
"Gulfs" area	2 Nov 1973	2 Oct 1983	1 Aug 2008
Gulf of Aden	1 Dec 1987	1 Apr 1989	*
Antarctic area	16 Nov 1990	17 Mar 1992	17 Mar 1992
North West European Waters	25 Sept 1997	1 Feb 1999	1 Aug 1999
Oman area of the Arabian Sea	15 Oct 2004	1 Jan 2007	*
Southern South African waters	13 Oct 2006	1 Mar 2008	1 Aug 2008
Annex II: Noxious Liquid Substances			
Antarctic area	30 Oct 1992	1 Jul 1994	1 Jul 1994
Annex IV: Sewage			
Baltic Sea	15 Jul 2011	1 Jan 2013	**
Annex V: Garbage			
Mediterranean Sea	2 Nov 1973	31 Dec 1988	1 May 2009
Baltic Sea	2 Nov 1973	31 Dec 1988	1 Oct 1989
Black Sea	2 Nov 1973	31 Dec 1988	*
Red Sea	2 Nov 1973	31 Dec 1988	*
"Gulfs" area	2 Nov 1973	31 Dec 1988	1 Aug 2008

North Sea	17 Oct 1989	18 Feb 1991	18 Feb 1991
Antarctic area (south of latitude 60 degrees south)	16 Nov 1990	17 Mar 1992	17 Mar 1992
Wider Caribbean region including the Gulf of Mexico and the Caribbean Sea	4 Jul 1991	4 Apr 1993	1 May 2011
Annex VI: Prevention of air pollution by ships (Emission Control Areas)			
Baltic Sea (SO _x)	26 Sept 1997	19 May 2005	19 May 2006
North Sea (SO _x)	22 Jul 2005	22 Nov 2006	22 Nov 2007
North American ECA (SO _x and PM)	26 Mar 2010	1 Aug 2011	1 Aug 2012
(NO _x)	26 Mar 2010	1 Aug 2011	***
United States Caribbean Sea ECA (SO _x and PM)	26 Jul 2011	1 Jan 2013	1 Jan 2014
(NO _x)	26 Jul 2011	1 Jan 2013	***

Status of multilateral conventions and instruments in respect of which the International Maritime Organization or its Secretary-General perform depositary or other functions as at 31 December 2002.

* The Special Area requirements for these areas have not yet taken effect because of lack of notifications from MARPOL Parties whose coastlines border the relevant special areas on the existence of adequate reception facilities (regulations 38.6 of MARPOL Annex I and 5(4) of MARPOL Annex V).

** The new special area requirements, which entered into force on 1 January 2013, will only take effect upon receipt of sufficient notifications on the existence of adequate reception facilities from Parties to MARPOL Annex IV whose coastlines border the relevant special area (regulation 13.2 of the revised MARPOL Annex IV, which was adopted by resolution MEPC.200(62) and which entered into force on 1 January 2013).

*** A ship constructed on or after 1 January 2016 and is operating in these emission control areas shall comply with NO_x Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.

Appendix 2

Summary of shipping-related provisions in China's Clean Air Law Amendments (Final, August 29, 2015)

Provision	Regulated area	Responsible agency
<i>Air emission standards for vessels</i>		
Ch. 4, Art. 62	- Vessels must be certified for meeting national air emission standards in order to operate	Certification agencies (e.g., CCS)
Ch. 7, Art. 112	- Prohibit forging of vessel emission testing results	MSA
<i>Marine fuel standards</i>		
Ch. 4, Art. 63	- Inland waterway vessels and river-sea vessels should use general diesel - OGVs at berth should use fuels that comply with requirements for meeting air quality control needs	Not specified
Ch.4, Art. 65	- Prohibit the sale of nonconforming marine, vehicle and non-road fuels - Prohibit the sale of residual oil or heavy oil for use on inland waterway vessels, river-sea vessels or non-road equipment	AQSIQ, SAIC (motor and non-road fuels) MOT, Fishery Administration (marine fuels)
Ch. 7, Art. 103	- Entities that sell non-compliant motor and non-road fuels will be imposed a fine of up to 1 to 3 times the economic value of the non-compliant products	AQSIQ, SAIC
Ch. 7, Art. 106	MSA and Fishery Administration to penalize ships that use non-compliant marine fuels; the fine should be not less than RMB 10k or not more than RMB 100k	MOT, Fishery Administration
Ch. 7, Art. 104	Prohibit import of nonconforming marine fuels; non-compliant entities t will be imposed a fine of up to 1 to 3 times the economic value of the non-compliant products	CIQ
<i>Shore power</i>		
Ch. 4, Art. 63	- New terminals should be shore-power ready - Existing terminals should be retrofitted with shore power facilities - Ships calling at Chinese ports should give priority to using shore power	Not specified
Ch. 4, Art. 64	- MOT can designate control zones for shipping air emissions along coastal waters; all ships entering these zones must comply with shipping-related requirements	MOT
<i>Others</i>		
Ch. 4, Art. 60	Promote retirement of high-emission vessels	Not specified

AQSIQ: General Administration of Quality, Inspection and Quarantine of China
Classification Society
SAIC: State Administration for Industry and Commerce
Transportation

CCS: China
MOT: Ministry of

The draft law can be found at: http://big5.gov.cn/gate/big5/www.gov.cn/zhengce/2015-08/30/content_2922326.htm

Appendix 3

Ministry of Transport
Shipping and Port Pollution Prevention and Control
Special Project Implementation Plan
(Released on August 31, 2015)

Highlights of air emission-related provisions

1. 2020 Goals:
 - Reduce sulfur oxide (SO_x), nitrogen oxide (NO_x) and particulate matter (PM) pollution in the three major port regions in China by 65%, 20% and 30%, respectively, compared to 2015 levels
 - 90% of harbor crafts, government vessel fleet to use shore power at berth
 - 50% of terminals serving container ships, Ro-Ro passenger vessels and cruise ships are equipped with on-shore power infrastructure

2. Set up Emission Control Area (ECA) for control of SO_x, PM and NO_x from ships:
 - By end 2015, MOT to issue implementation plan for setting up ECAs in Pearl River Delta, Yangtze River Delta, and Bohai Bay waters
 - Key ports in the three ECAs to become ECA demonstration ports
 - By end 2018, review effects of the demonstration projects to determine the need for tightening ECA requirements, extending the ECA boundary, and undertaking other additional measures

3. Promote the use of on-shore power
 - By end 2015, announce new on-shore power demonstration ports
 - By end 2016:
 - Coordinate with relevant agencies to establish a sale/pricing mechanism for the use of on-shore power
 - Enhance standards relevant to on-shore power infrastructure and improve incentive policies for promoting on-shore power
 - By end 2018, pursue construction of on-shore power infrastructure at key ports in the three key regions, and promote the use of on-shore power at other ports.

4. Promote the use of LNG
 - By end 2015, announce plans for building LNG bunkering terminals along Yangtze River, Xi Jiang, and Beijing-Hangzhou Canal
 - By end 2016:
 - Complete development of the Design Regulation for LNG Terminals
 - Develop the Design Regulation for LNG Bunkering Terminals
 - By end 2017, establish LNG standard framework for shipping
 - By end 2018:
 - Accelerate construction of LNG bunkering facilities and associated infrastructure
 - Optimize relevant technical regulations and standards
 - Expand the scope of pilots for LNG-powered vessels
 - Conduct pilots to promote the use of LNG-powered harbor crafts

5. Establish air pollution-related standards for vessels and ports
 - By end 2015:
 - MOT to support MEP in establishing air emission standards for domestic vessels
 - MOT to support General Administration of Quality Supervision and Quarantine and the National Energy Agency to amend national marine fuel standards
 - By end 2017, MOT to support MEP in amending vapor recovery standards at ports based on China's specific conditions
 - By end 2020:
 - MOT to release standards for retrofitting vessels to use natural gas
 - Establish technical standards for shipping air emission monitoring technologies
 - MOT shall complete requirements for retrofitting or retiring vessels not meeting with air emission-related standards
 - All coastal vessels and inland waterway vessels shall comply with all air-related emission standards by 2018 and 2021 respectively

6. Enhance research and enforcement capacity
 - Enhance transportation-related environmental monitoring and regulation framework
 - By end 2016, complete research on vessel air pollution-related data, vessel emission after-treatment technologies, vessel and port air pollution dispersion modeling and impact assessment.
 - By end 2017, complete research on shipping air pollution monitoring technologies
 - By end 2018, complete research on the technologies applicable for ships to reduce energy consumption, air pollution, vapor recovery, etc.

7. Improve efficiency of the logistic chain
 - Address the "last mile" issue of connecting railway to ports
 - Promote intermodal freight transport, including ship-to-rail, ship-to-ship, use of ro-ro containers
 - By 2020, provide ship-to-rail container services at major container shipping ports and promote on-dock rail services

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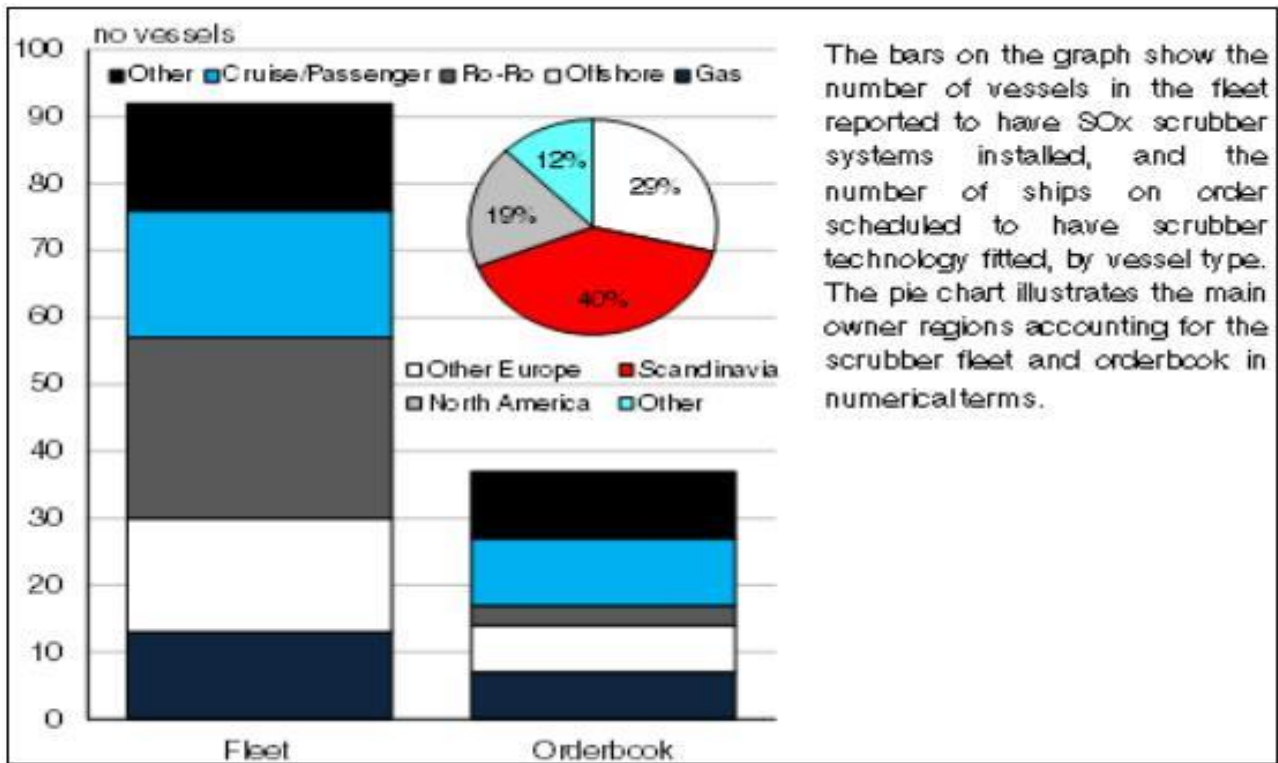
- i <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx>
- ii NO_x emission limits are set for diesel engines depending on the engine maximum operating speed (n, rpm). A detailed account can be found at <https://www.dieseln.net.com/standards/inter/imo.php>
- iii The Greenhouse Gas (GHG) Protocol, developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD), sets the global standard for how to measure, manage, and report greenhouse gas emissions. See more at: <http://www.ghgprotocol.org/>
- iv Trude Pettersen (2013), “Fifty Percent Increase in Northern Sea Route,” Barents Observer, December 3, 2013. Available at: barentsobserver.com/en/arctic/2013/12/fifty-percent-increase-northern-sea-route-03-12
- v See the IMO website for more information about MARPOL and the various areas it covers: www.imo.org
- vi IMO Tier III goes into effect in January 2016. Tier III engines have much lower maximum NO_x emissions (3.4 g/kWh at lowest speed). Vessels with a keel-laid date on or after January 1, 2016 that travel in NO_x Emission Control Areas (ECA) will require IMO Tier III certified engines. When these vessels travel outside of NO_x ECAs, IMO Tier II will apply.
- vii The process of providing shoreside electrical power to a ship at berth while its main and auxiliary engines are turned off.
- viii All references to dollars (\$) are to United States of America dollars, unless otherwise stated.
- ix The German Shipowners’ Association (VDR), the German Shipbuilding and Ocean Industries Association (VSM), the Association of German Seaport Operators (ZDS) and the German Shipbrokers’ Association (ZVDS).
- x A full account of Emission Standards worldwide can be found here: <http://www.ukpandi.com/knowledge/article/emission-standards-sox-nox-130578/>
- xi Find LNG International Legal Framework here: https://www.dnvgl.com/Images/legal%20framework%20internet%2023%202%202015_tcm8-13820.pdf
- xii The notation PM₁₀ is used to describe particles of 10 micrometers or less.
- xiii <https://www.dnvgl.com/maritime/lng/index.html>
- xiv Find an extensive list of LNG fuelled vessels in operation and on order here: https://www.dnvgl.com/Images/2015-07-01%20World%20LNG%20fuelled%20fleet_tcm8-5550.pdf
- xv Rolls-Royce (2013), *Carbon Disclosure Project – 2012 Investors response*.
- xvii Fracking is the process of drilling down into the earth before a high-pressure water mixture is directed at the rock to release the gas inside. Water, sand and chemicals are injected into the rock at high pressure which allows the gas to flow out to the head of the well. The process is carried out vertically or, more commonly, by drilling horizontally to the rock layer. The process can create new pathways to release gas or can be used to extend existing channels. More information can be found here: <http://www.bbc.com/news/uk-14432401>

xviii DNVGL. The new reference for LNG propulsion

xix DNVGL. The new reference for LNG propulsion

xx DNVGL. The new reference for LNG propulsion

xxi Graph: Uptake of Sox Scrubber Systems:



The bars on the graph show the number of vessels in the fleet reported to have SOx scrubber systems installed, and the number of ships on order scheduled to have scrubber technology fitted, by vessel type. The pie chart illustrates the main owner regions accounting for the scrubber fleet and orderbook in numerical terms.

Source: Parry-Jones, S. (2014), *2015 SOx Limits: Is The World Fleet Scrubbing Up?* Shipping Intelligence Network 2010.