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Chapitre 6

Liquified natural gas as a marine fuel: the case of the baltic sea region

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Abstract

The International Maritime Organization (IMO) has rather recently significantly amended the International Convention on Prevention of Pollution by Ships (better known by the acronym MARPOL), which firmly controls pollution levels related to the shipping industry. These new/updated legal provisions in turn exercise significant influence on the type of energy and fuel used during shipping operations, as well as the issue of "permitted emissions". For ship-owners, in order to ensure compliance with these new regulatory demands changes in their current business models are needed. Briefly, three main options are standing out: a) integrating an emission abatement technology, such as a scrubber b) opting for a more environmental friendly energy resource such as liquefied natural gas (LNG) c) using low sulphur fuel such as MGO (marine gas oil) or MDO (marine diesel oil). For the time being, LNG is considered as a very attractive option and is gaining more and more momentum. It is becoming increasing available, since bunkering facilities/infrastructure are created with a very satisfactory pace; LNG's physical properties also allow to easily meet the most stringent environmental requirements, without any significant additional costs. The «Go LNG» Project, which will be the epicentre of the analysis in hand, aims to promote both demand and accessibility of LNG in the Baltic Sea Region (BSR). A strategy for a smoother and more efficient use of LNG as a fuel for transport is an action of priority in order to enable the so-called "blue transport corridors" and improve the environmental footprint of transport endeavours.

Keywords: "Go LNG" Project, Liquefied Natural Gas (LNG), Baltic Sea Region (BSR), Blue Corridor Strategy.

Introduction

When the discussion revolves around the topic of "clean" technological solutions for the shipping industry, the Baltic Sea Region (BSR) (comprising Denmark, Finland, Estonia, Germany, Latvia, Lithuania, Norway, Sweden and Russia) is clearly a leading region of the world (Dalaklis et al., 2017). The BSR is, since 2005, an Emissions Control Area (ECA) under the International Convention for the Prevention of Pollution from Ships (MARPOL). Initially, this restricted the emission of sulphur oxides from ships' combustion engines to the air, to an amount equivalent to 1.5 % m/m sulphur present in the fuel. This level was made progressively more stringent, with only 1.0 % m/m fuel sulphur equivalent being allowed since 2010, and only 0.1 % m/m allowed since 2015. The cumulative

result of these regulations is that ship-owners now have to either remove the excessive sulphur from the exhaust gases of the engine by scrubbers, or to resort to fuels containing 0.1 % m/m sulphur or less. The latter path leaves the option between liquid fuel oils with low sulphur content, or alternative fuels such as liquefied natural gas (LNG), liquefied petroleum gas (LPG), biofuels, or synthesised energy carriers that naturally contain low levels of sulphur. To cut a rather long way short, three main options (which will be briefly discussed next) are standing out: a) integrating an emission abatement technology, such as a scrubber b) opting for a more "environmental friendly" fuel, such as LNG c) using low sulphur fuel such as marine gas oil (MGO) or marine diesel oil (MDO) (Dalaklis, 2016; Madjidian et al., 2018).

Scrubbers typically absorb the sulphur oxides (SOx) that are formed during fuel combustion into a liquid or solid phase and are subsequently binding the sulphur in a different chemical form. The so-called "wet-scrubber" systems (in open-loop configuration) can use sea water directly to absorb and bind the sulphur oxides, which are associated with a very negative impact towards the environment. This requires large water flow rates and to discharge the "wash water" directly to the sea. Wet-scrubbers also have the advantage of removing exhaust gas particulate matters by around 70-90 % (Lloyds Register, 2012). Some of the pollutants contained in the wash water are removed in terms of a sludge, that can be disposed more appropriately on designated facilities on land. The wash water discharged to the sea must be monitored for its acidity and for the presence of polycyclic aromatic hydrocarbons (PAHs) and turbidity (which indicates the presence of soot). Despite these measures, open-loop wet scrubbers discharge a proportion of these pollutants to the sea. The sea may thus be contaminated to some extent with sulphuric acid, products of incomplete combustion or unburned fuel, as well as various metals and metal oxide particles originating from either the engine or the fuel (e.g. aluminium silicate originating from fuel refinery catalysts, cat fines). Some of these emissions appear to be sufficiently problematic to suggest that widespread open-loop seawater scrubbing may be an unsustainable method to deal with the problem of ships' emissions to air.

Closed-loop water scrubbing systems recirculate their wash water within a water cycle on-board the ship and typically use sodium hydroxide or magnesium oxide to bind the sulphur and neutralise its acidity. A closed-loop scrubber can operate without discharge to the sea (for a limited amount of time). Yet, using current designs, they still need to remove wash water from the cycle, in order to limit sodium sulphate concentrations and crystallization within the wash water system. This requires them to eventually discharge their wash water to a tank, and when this is full, to the sea. The problem of sea contamination may be reduced due to improved sludge removal, but not entirely solved. An alternative to wet scrubbers, are dry scrubbers employing calcium hydroxide to absorb sulphur oxides and transform them via chemical reaction into calcium sulphate or calcium sulphite, or activated coke (Haase & Koehne, 1999) to absorb them in the form of sulphuric

acid. Dry scrubbers do not cause seawater contamination from wash water, and may provide more environmentally sustainable alternatives to wet scrubbing systems. Dry scrubbers also have the advantage of being compatible with low-pressure SCR systems for simultaneous nitrogen oxides (NOx) reduction, since they do not cool the exhaust gases. They have been reported to be 80 % effective in removing particulate matters (Lloyds Register, 2012).

Low sulphur fuel oils, such as Low Sulphur Marine Diesel Oil (LSMDO) or Low Sulphur Heavy Fuel Oil (LSHFO), can facilitate compliance with the sulphur limits in ECA, without major technical changes to ship engines. It is expected that the price of low sulphur fuel oils will be higher than the one of high sulphur oils. Small technical adaptions for operating engines on low sulphur fuels are also required. Low sulphur fuel oils are derived from crude oil, and thus require removal of naturally present sulphur in order to meet the 1.0 % m/m fuel sulphur requirement. In order to obtain a low sulphur content, LSHFO consists to a large extent of the residues obtained from Fluid Catalytic Cracking (FCC) fuel refining processes. Such processes employ aluminium silicates (zeolites) as catalysts (Vogt & Weckhuysen, 2015), which can remain present in the final LSHFO product. Such "cat fines" are extremely hard particles, that can cause excessive wear and rapid failure of engine components. Fuel standardisation (ISO 8217, 2017) limits the presence of aluminium plus silicon to 60 mg/kg, within LSHFO, but engine manufacturers typically recommend no more than 10 mg/kg (MAN Diesel & Turbo, 2015). Fuel cleaning equipment in the form of a separator must thus be operated appropriately to meet this specification and ensure proper engine operation. In addition to this, the cylinder lubricating oil base number (BN) needs to be reduced when switching from high sulphur fuels to low sulphur fuels. This is to avoid the occurrence of calcium deposits in the engine, and to ensure that a healthy amount of acid corrosion keeps an open graphite structure in the cylinder liner of the engine, to ensure suitable lubrication (MAN Diesel & Turbo, 2014).

A third option can be achieved via LNG, which is kept in its liquid state through the application of very low (cryogenic) temperature (near -163 Celsius). When LNG is exposed to the atmosphere, it will warm and return to its natural gaseous state; this is done by boiling and evaporating. To maintain the required properties, LNG can be stored within a high pressure tank (10 bar or more), or within an "ordinary" atmospheric tank depending upon the fuel system demands (Dalaklis et al., 2017). LNG typically contains only very low levels of sulphur, and meets the requirements for 0.1 % m/m sulphur or less. In LNG, sulphur usually exists in the form of hydrogen sulphide (H2S), but is usually removed from the natural gas prior to its liquefaction. In order to employ LNG as a fuel for ship engines, a shipboard LNG tank, fuel system and gas injectors need to be installed. Ship engines can be operated on LNG using both Diesel and Otto cycle combustion modes. LNG engines and fuel systems can be installed as part of new ship building, or as retrofit projects for existing engines on ships. The environmental performance

of LNG, its economic considerations, and an infrastructure strategy for further expansion of LNG within the BSR will be discussed in the ensuing sections.

Enviromental perormance of LNG

LNG consists predominantly of methane (CH_4), the simplest alkane, but can include various higher alkanes, such as ethane (C_2H_6) or propane (C_3H_8). Components such as ethane are often included in LNG up to its allowed specification limit, since they may be available at a lower cost. Pure methane boils from liquid phase at a temperature of 112 K (Atkins & De Paula, 2001). The boiling point of LNG is very similar to that of methane, and it is gaseous at standard conditions of temperature and pressure. Its latent heat of evaporation of 511 J/kg (Kim et al., 2015) allows it to be stored at its boiling point, permitting a given amount of heat to evaporate a portion of the LNG, while the rest is kept liquid. Nevertheless, suitable insulation, a liquefaction plant, and associated energy requirements are necessary to keep LNG liquid over long periods of time. Methane, has a higher hydrogen to carbon ratio than MDO, or HFO (see Table 1 that follows). This has important implications for its environmental performance when combusted in an engine. Firstly, less carbon dioxide (CO_2) is emitted when setting free a specific amount of energy during combustion, compared to HFO. Methane releases about 28 % less CO_2 than HFO. The HFO used for comparison assumes an overall carbon to hydrogen ratio of 1.51, derived from the data obtained by Garaniya et al. (2018), and a Lower Heating Value (LHV) of 42.7 MJ/kg (WinGD, 2018). Pure methane has a heating value of 50.1 MJ/kg, which can be calculated from the enthalpies of formation of the reactants and products (Glassman & Yetter, 2008). This leads to CO_2 emissions factors of 54.84 t CO_2/TJ for methane, and 76.28 t CO_2/TJ for HFO. Secondly, methane inherently has a lower adiabatic flame temperature T_{ad} than HFO. Since the formation of nitrogen oxides (NOx) in diesel engines is dominated by the occurrence of peak combustion temperatures (Heywood, 1988), T_{ad} provides a simple means of comparing the NOx forming propensity of these two fuels. The flame temperature for methane and HFO were calculated using the combustion reactions and lower heating values (LHV); they are presented in Table 1. T_{ad} was calculated for a stoichiometric fuel and air mixture at constant pressure without dissociation of the combustion products. The combustion product mixture enthalpy was estimated using a constant ratio of specific heat evaluated at $T_{Cp} = \frac{1}{2} (T_i + T_{ad})$, where T_i was the initial temperature of the reactants (298 K), and T_{ad} was the adiabatic flame temperature. The procedure for such a simplified calculation of the adiabatic flame temperature is described by Turns (1996).

Table 1. Salient combustion related properties for LNG and MGO

Name	Simplified chemical formula	Reaction	LHV [MJ/kg]	T ad [K]	CO_2 emission $[CO_2/TJ]$
Methane	CH4	CH4+2·(O2+3.76·N2) →CO2+2·H2 O+7.52·N2	50.1	2283	54.84
HFO	CH1.5	CH1.51+1.38·(O2+3.76·N2)→ CO2+0.75·H2 O+5.19·N2	42.7	2450	76.28

Thirdly, methane is gaseous at standard conditions, and can therefore be used to readily form a lean fuel and air mixture with the intake air of an engine, prior to compression. This allows LNG to be burned as a lean fuel and air mixture, whose combustion temperature can be controlled via its fuel to air ratio. Typically, such a mixture is ignited by a small pilot injection of HFO, or a spark. The bulk of the mixture is typically combusted by deflagration, in what is commonly described as an Otto cycle engine. This has the advantage of eliminating fuel-rich zones and high combustion temperatures present in burning jets, resulting in a significant reduction of particulate matter (PM) and NOx formation. The emissions reduction with respect to conventional diesel engines operating on HFO is as high as 95% in the case of PM, and 85% in the case of NOx (Miller & Bowman, 1989). This allows ships to meet IMO Tier III emissions regulations without requiring exhaust gas after treatment. A problem with this technology is that premixing of fuel and air in the engine prior to full compression and the low combustion temperatures associated with burning lean fuel air mixtures, can lead to quenching of the combustion along the walls and in any crevice volumes of the cylinder. The result is the emission of unburned methane and is commonly termed "methane slip". Methane is a powerful GHG and its emission is problematic, though it is currently not regulated under IMO International Convention for the Prevention of Pollution from Ships (MARPOL, Annex VI). The latest IPCC report estimates its cumulative GHG forcing effect over 20 years to be 84 times as severe as that of CO_2, and its cumulative GHG forcing effect over 100 years to be 28 times as severe as that of CO_2 (IPCC, 2014). Its lifetime in the atmosphere is estimated to be 12.4 years, meaning that it has a severe impact in the years directly ensuing its release. Its GHG effect is thus significant, contrary to CO_2, strongly time dependent. Although it is not regulated as of now, it threatens to undermine the CO_2 emission advantages of LNG over HFO in the short and medium term. Methane slip can be avoided if methane is burned as a high-pressure jet. This engine technology requires high pressure injection of methane, and thus its compression to pressures significantly above the cylinder pressure of the engine. It also requires a reliable source of ignition, which typically takes the form of a small pilot injection of a fuel that readily "auto ignites", typically HFO. This technology almost completely eliminates the occurrence of methane slip, but it requires additional emissions reduction technology such as Exhaust Gas Recirculation (EGR) or Selective

Catalytic Reduction (SCR) to meet IMO Tier III emissions regulations (MAN Energy Solutions, 2018). Fourthly, the volatility of LNG, is translated into the fact that it is easily emitted to the atmosphere via accidents, purging of fuel systems, safety relief of pressurized pipes or vessels. This is a significant disadvantage in terms of its GHG impact, when compared with liquid fuels.

In terms of its environmental performance, it is likely that LNG offers to be a bridging technology for more sustainable fuels in the future. It allows reducing emissions of sulphur completely, reducing the emissions of nitrogen oxides and somewhat reduce the CO_2 emission from ships. However, LNG from fossil sources will not reduce GHG emissions by considerably more than 28%, since the efficiency of LNG-fueled engines is currently similar to that of diesel engines operating on fuel oil. Switching to LNG on its own is thus an insufficient measure to meet the aims of IMO Resolution MEPC.304(72) of reducing carbon intensity by 40% from 2008 levels by 2030. LNG is also far from able to reduce carbon intensity by 70% from 2008 levels, which IMO Resolution MEPC.304(72) (IMO, 2018) requires by 2050. The use of LNG is thus likely to be most needed in the immediate future. Its environmental performance depends also on how LNG is used. At worst, methane emissions from LNG powered ships could efface its GHG advantage over HFO. At best, if the LNG methane is derived from biogas, or synthetically produced using energy from renewable sources, LNG could become an energy carrier for renewable energy and a bridging technology to facility the development of more renewable energy. Yet, even as an energy carrier, its strong GHG effect when released to the atmosphere, the energy losses associated with synthetic production of methane from renewable energy (Connolly et al., 2014) and its necessity for cryogenic storage and transport could become disadvantages in the long term.

Infrastructure strategy for LNG

LNG infrastructure in the BSR has to be designed strategically, so as to provide ships with suitable facilities for (safe and efficient) LNG operation. Starting to put all the blocks together, LNG needs to be made available to ships from bunker terminals. The distance between bunker terminals should be sufficiently short so as to provide both an environmental and an economic benefit over LSHFO. The basic environmental performance of LNG has been discussed in the previous section of this chapter (Environmental Performance of LNG), with a first principles calculation showing that methane releases about 28 % less CO_2 than HFO to provide the same amount of energy. If an LNG-powered engine has the same energy conversion efficiency as an HFO powered engine, this ship can, if sailing on LNG, travel a distance equivalent to 128 % of the distance it would have originally travelled on HFO, and emit the same amount of CO_2. The relevance of this assessment for the infrastructure strategy of the BSR is, that ships can

travel an additional distance of 28 % with respect to their usual route, to find an LNG terminal and refuel, before the additional distance travelled effaces the CO_2 benefit of LNG. Depending on their operational route, this yields a measure for the maximum distance at which LNG terminals should be spaced apart. From a CO_2 emission perspective, the distance at which LNG terminals should be positioned apart within the BSR, becomes a function of the distance which a ship can travel on LNG before having to refuel, and on its intended route. The distance which a ship can travel on LNG before having to refuel depends on the LNG tank capacity available, and off course on its fuel consumption rate. Large ships are typically designed to travel long distances without refueling. Their routes are longer and more likely to lead them past an LNG terminal. Smaller vessels are typically designed to travel shorter distances before having to refuel, and thus require more closely spaced LNG infrastructure for refueling. This leads to an LNG bunkering station network that has larger distances between bunkering facilities for large ships, and smaller distances between bunkering facilities for small ships. A generic overview of the BSR, and existing LNG bunker facilities (end of year 2018) is presented via Figure 1.

Figure 1. Existing LNG bunker facilities within the BSR (2018)
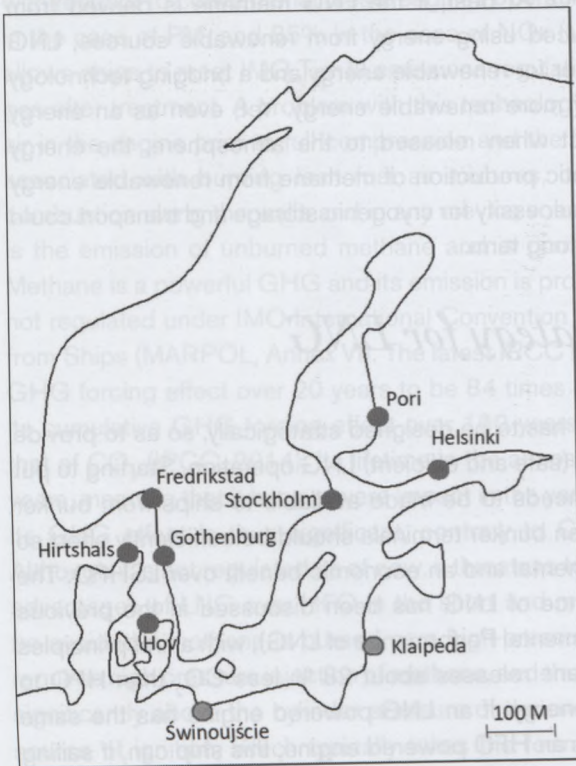
[Figure generated by the authors].

The additional distance a ship can travel in order to get access to an LNG bunker facility, can also be calculated from an economic point of view. This allows making an estimate of how closely LNG bunkering infrastructure needs to be spaced apart in order to provide an environment that is favorable for the installation of LNG powered ships. This critical LNG bunker station density can be illustrated using a simplified business case scenario for a ship operator: A bulk carrier, having power consumption of 14400 kW at its design speed of 14 knots (TEFLES 2012), travels from Tallinn, Estonia to Liepaja, Latvia. The round trip comprises approximately 621 nautical miles, and with a main engine efficiency of 50.8 % requires around 30 t of LSMGO. Assuming a price of 17.29 $/MMBTU (DNV-GL, 2018) for LSMGO, this journey costs around 74255 $ in fuel. To accomplish the same journey with LNG, with a main engine efficiency of 51.1 % requires around 26 t of LNG. Assuming a price of 10.79 $/MMBTU (DNV-GL, 2018) for LNG, this journey costs around 46060 $ in fuel. Switching to LNG thus allows saving 45 $ per nautical mile covered, which is around 38 % of the total fuel cost. Adding a distance of up to 236 nautical miles to the journey is thus worthwhile for the ship, if this allows refueling with LNG. This would allow the ship to travel the additional 98 nautical miles to reach the Klaipeda LNG terminal, and still operate more cheaply than on LSMGO. An overview of three (3) such examples for different ship types is provided in Table 2.

Table 2. Overview of additional distance worth travelling for various ship types to bunker LNG

Ship type	Cruise speed [knots]	Cruise power [kW]	Route Distance [M]	Additional Distance [M]	Price MDO [$/MMBTU]	Price LNG [$/MMBTU]
Bulk carrier	14	14400	621	236	17.29	10.79
Car carrier	16.5	7618	270	103	17.29	10.79
Container ship	16	9992	810	308	17.29	10.79

The additional distances shown in Table 2 provide a simple indication of how closely spaced LNG terminals need to be in order to provide the critical LNG bunker location density necessary to make investing in LNG powered vessels advantageous for ship operators. The values given herein are similar to the recommendation of 400 km given for LNG maritime ports by the trans-European transport network (TEN-T) core network (EU Commission, 2013). The additional distance which a vessel is able to travel to reach an LNG terminal is strongly dependent on the price difference between SFMGO and LNG. In order to evaluate how the critical additional distance that a vessel can travel changes with bunker prices, a sensitivity analysis on SFMGO and LNG prices was conducted using a Monte Carlo Simulation (MCS) software. SFMGO and LNG prices were

varied individually over 10000 trials. A normal distribution was assumed having a standard deviation of 25 % of the price values stated above. The results showed that even with these variations the additional distance worthwhile taking for the bulk carrier was above 150 nautical miles for 95 % of the cases, allowing the vessel to reach the port of Klaipeda.

Figure 2. Distribution of "additional distance worth travelling for LNG" for a bulk carrier on a 621 M route
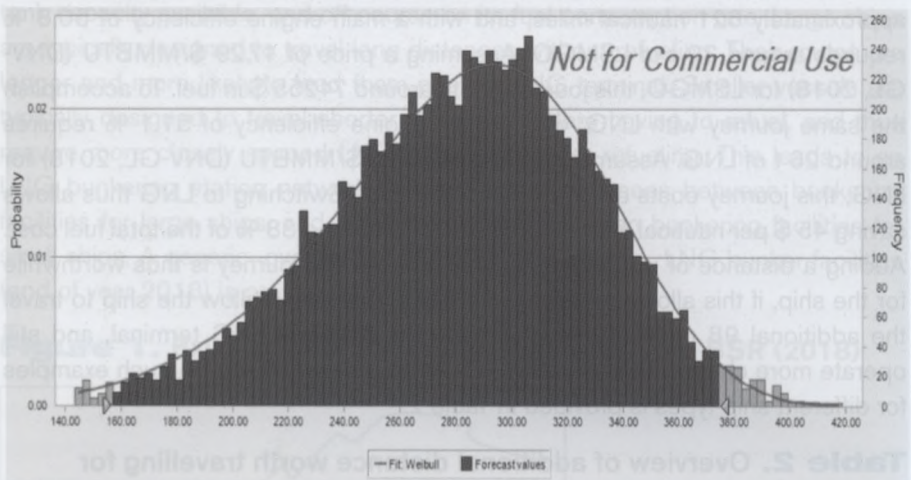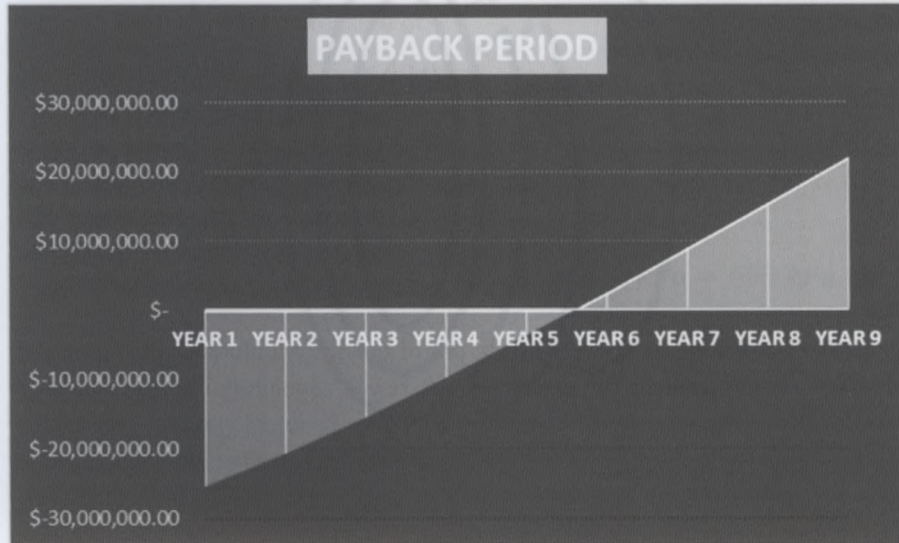

[Figure generated by the authors]

The distance between the only two large scale LNG terminals in the BSR is that between Swinoujscie and Klaipeda is currently 262 nautical miles. This is within the range of distances observed in the examples shown in Table 2. Smaller scale LNG terminals currently already exist at the ports of Helsinki, Pori, Stockholm, Nynäshamn, Gothenburg, Hirtshals, Hov, Lysekil, and Fredrikstad. As the examples above showed, smaller scale LNG terminals will need to be more closely spaced in order to provide an economic incentive to owners of small vessels to operate on LNG, since smaller vessels typically cover smaller distances and are less likely to pass one of the major LNG bunker facilities on their way. For large scale commercial vessels sailing far beyond the BSR, the BSR entry paths of the Skagerrak, Kattegatt, the Great Belt, and the Øresund are strategically placed as LNG bunkering locations, since these vessels have to pass them on their way into the BSR. These areas already feature a number of LNG bunkering facilities, and there need to be several of them, in order to provide the necessary competition, given their privileged location at the entry to the BSR. To further assess the economic benefits from the ship-owners point of view, the payback period was calculated using one of the above vessel examples. Assuming that a large LNG tank was installed on the vessel, which would allow it to sail 31075 nautical miles on LNG, and assuming a specific LNG tank cost of

2500 $/m³, a total cost for the LNG engine and fuel systems of 3.2 M$, a total cost for the LNG propulsion system amounted to around 32 M$.

**Figure 3.** Payback period for LNG installation on new ship

[Figure generated by the authors]

Figure 3 demonstrates that the payback period for such an LNG powered vessel would be around 5.6 years, assuming a net discount rate of 0.45. The payback period can be reduced significantly if the tank capacity is reduced. If the tank capacity is reduced to only accommodate the LNG capacity for one round trip of 621 nautical miles, the payback period is reduced to under one year. This highlights the economic benefits of sufficient LNG bunker infrastructure for vessel owners.

Salient technical aspects of LNG bunkering infrastructure

The low storage temperature of LNG of around 77 K (-196° C) or below at atmospheric pressure, means that it has to be contained by materials withstanding these conditions. The commonly used structural material carbon steel with its Body Centered Cubic (BCC) crystal structure becomes brittle at such low temperatures, and more ductile materials with Face Centered Cubic (FCC) crystal structure, such as austenitic steels containing 12 % chromium or 9 % nickel should be used (Kim et al. 2015).

Figure 4. LNG refueling connector
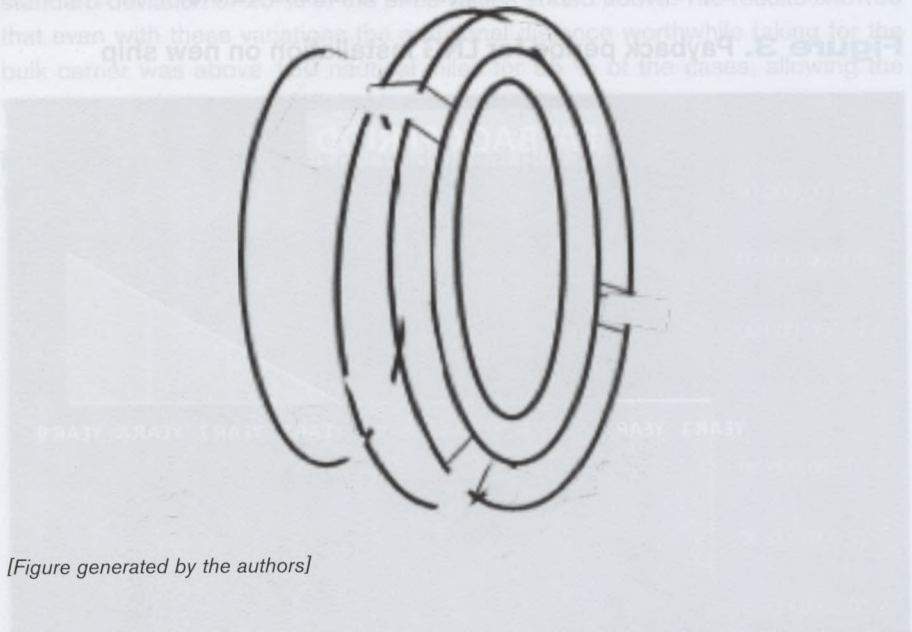
[Figure generated by the authors]

LNG is stored around atmospheric pressure, but pumping of the fluid will require pressure differentials in order to transport the LNG between facilities. The minimum pressures necessary for pumping can be calculated using the dynamic pressure of the fuel when pumping at the minimum speed necessary. Current proposals at the EU Commission have been quoted at 350 m3/h, and a maximum flow speed of 10 m/s. Assuming an LNG density of 470 kg/m3 (IMO Maritime Safety Committee, 2014), a simplified application of Bernoulli's equation, yields a dynamic pressure 24 kPa as per equation 1.

$$P_{dynamic} = \frac{1}{2} \cdot \rho \cdot u^2 = 24 \; kPa \quad (1)$$

To this initial estimate of pressure should be added reasonable estimates for static pressure that could result from a pressure head building up within the tank. Assuming a maximum tank height h of 25 m, and a gravitational acceleration g of 9.81 m/s2 the maximum static pressure would be estimated as 115 kPa according to equation 2.

$$P_{static} = \rho \cdot g \cdot h = 115 \; kPa \quad (2)$$

The minimum total pressure for refueling equipment would thus be:

$$P_{total} = P_{dynamic} + P_{static} = 24 \; kPa + 115 \; kPa = 139 \; kPa \quad (3)$$

In addition to the above considerations, refueling equipment should be able to withstand the dynamic pressure fluctuations induced in the pipe during pump

upstarts and valve closures. The resulting maximum pressure during such acceleration or decelerations of the fluid may be calculated from first principles using equations 4 and 5. Assuming that the length of the pipe may be up to 50 m, and that the acceleration of 20 m/s accelerates from rest to full flow velocity within 0.5 s, this yields a pressure of:

$$F = m \cdot a = P_{acceleration} \cdot A \quad (4)$$

$$P_{acceleration} = \frac{m \cdot a}{A} = \rho \cdot l \cdot a = 470 \ kPa \quad (5)$$

The maximum pressure is thus:

$$P_{max} = P_{total} + P_{acceleration} = 139 \ kPa + 470 \ kPa = 609 \ kPa \quad (6)$$

A safety factor should be applied to the above value to accommodate deviation from the above conditions. Given the large impact of failure of the refueling equipment, a safety factor of around 5 may seem reasonable, thus resulting in a pressure resistance to around 3 MPa.

In addition to the above specifications for temperature and pressure, dimensions should be specified to keep refueling times at a reasonable level. The refuelling time can be calculated using the relation between tank volume, refueling flowrate and time in equation 7.

$$Q = \frac{V_{tank}}{t} = \frac{1950 \ m^3}{3h} = 650 \ {m^3}/{h} \quad (7)$$

If the LNG velocity should be limited to say 10 m/s, then the diameter of the refueling hose can be calculated using equation 7:

$$D_{hose} = 2\sqrt{\frac{Q}{u_{max.}}} = 2\sqrt{\frac{650 \ {m^3}/{h}}{10 \ m/s}} = 0.27 \ m \quad (7)$$

A typical hose size of 0.27 m diameter can thus be recommended to fulfil the above requirements. Before moving to a different direction, it is useful to note that an LNG refueling system should consist of a minimum of two pipes: one pipe to carry the LNG in the direction of the LNG flow, and one pipe to carry the gas vapor in the opposite direction, in order to avoid significant pressures building up in the tanks (Swedish Marine Technology Forum, 2013). Additionally, an "earthing" cable needs to be present to safely earth LNG ship and bunkering facility prior to connection. Dry break-away couplings should be used in order to avoid leakage of LNG in emergency situations in which the LNG refueling pipe is ruptured (Swedish Marine Technology Forum, 2013).

The "Go LNG" project

A strategy for the LNG infrastructure requirements is being developed as part of the EU funded "Go LNG" project (http://www.goIng.eu/). Aim of the project is to bring together stakeholders from the BSR region to develop LNG infrastructure, business models, research and education and to provide an LNG developments strategy that can further the aims of the EU Clean Fuel Strategy and the Directive on the Deployment of Alternative Fuels (EU Parliament and Council, 2014). As part of this work, a Blue Corridor Strategy is being developed to support the development of a maritime transport corridor in the BSR (Madjidian et al., 2018). This strategy takes into consideration the "TEN-T Core Network and "Motorways of the Sea" concepts (EU Commission, 2013) to develop an efficient transport network making use of several modes of transport. Under the EU Commission plans, a North Sea - Baltic Core Network Corridor will be established, connecting the Baltic sea ports of Tallinn, Riga, Ventspils, Klaipeda. The establishment of LNG bunkering facilities for sea ports forms part of the TEN-T Core Network strategy.

Summary and Conclusion

LNG is one of several possible options for ships in the BSR to be able to meet the requirements Emissions Control Area (ECA) under the International Convention for the Prevention of Pollution from Ships (MARPOL). It is likely to be an environmentally and economically attractive option, since scrubbers have considerable environmental impact, and LSMGO is likely to be expensive. LNG has the added advantage of reducing CO_2 emissions with respect to LSMGO, yet caution is warranted not to reduce or efface this advantage by the release of methane, either through excessive methane slip, accidents or purging as part of the vessel's operational procedures. Yet, for the deployment of LNG to be successful in the short and medium terms, a critical amount of LNG infrastructure needs to be established to warrant environmental and economic benefits. Thus, the distance in between LNG bunkering facilities should not exceed a critical distance. This distance depends on the CO_2 advantage of LNG, as well as its economic benefits, and thereby the LNG and LSMGO bunker prices. It is also important that technical standards for LNG bunkering are established as soon as possible under the IGF code, in order to facilitate safe LNG technology and compatible standards.

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