UNIVERSITY OF PIRAEUS

DEPARTMENT OF MARITIME STUDIES – MSc in Shipping Management

Alternative sources of energy as marine fuels; the effect on the environment and the financial perspectives for a more sustainable future in the shipping industry.

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Thesis statement

Which was submitted to the Department of Maritime Studies of University of Piraeus as part of the requirements for obtaining a postgraduate degree in Shipping Management.

Piraeus

September 2021

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Acronyms

AMP Alternative Maritime Power
CH4 Methane
CI Cold Ironing
CNG Compressed Natural Gas
CO_2 Carbon Dioxide
CO Carbon Monoxide
ECA Emission Control Area
EEDI Energy Efficiency Design Index
EEOI Energy Efficiency Operational Indicator
EPA Environmental Protection Agency
GHG Greenhouse Gas
HFO Heavy Fuel Oil
IAPH International Association of Ports and Harbours
IGC International Gas Code
IGF International Code of Safety for Gas-Fuelled Ships
IMO International Maritime Organization
ISM Code International Safety Management Code
ISO International Organization for Standardization
kW kilowatt
LNG Liquefied Natural Gas
LPG Liquefied Petroleum Gas
MARPOL International Convention for the Prevention of Pollution from Ships
MARSEC Maritime Security
MDO Marine Diesel Oil
MERPAC Merchant Marine Personnel Advisory Committee
MGO Marine Gas Oil
NO_x Nitrogen Oxides
PM Per Million
SO_x Sulfur oxides
SOLAS Safety of Life at Sea
US United States

Alternative sources of energy as marine fuels; the effect on the environment and the financial perspectives for a more sustainable future in the shipping industry.

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Keywords: maritime transport; LNG; alternative fuels; sustainability; emissions, cold ironing, ammonia, LPG, hydrogen, methanol;

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1. Introduction

Maritime shipping is considered as the most eco-friendly and fuel-efficient method of transport in ton-miles terms and moves about 90% of the worldwide trade (UNCTAD, 2020) [1]. The third GHG study (IMO, 2014) [2] estimates that shipping accounts for approximately 2.2% of the global anthropogenic CO2 emissions, addressing a 0.5% decrease from the second GHG study measures (IMO, 2009) [3]. However, the sector has seen increasing pressure, through new guidelines to improve its environmental performance, especially considering its commitment to harmful contamination emissions on human wellbeing. Sea transport represents 5–8% of the worldwide SOx emissions (Eyring et al., 2005) [4], and around 15% for NOx (Corbett et al., 2007) [5], while PM emissions from transportation close to coastlines and ports have been connected to fatalities attributed to respiratory health issues. The IMO is regulating the greatest sulfur limits in fuel through the changed MARPOL Annex VI, which additionally assigned sulfur emission control areas (SECA) where more tight limits apply. Current SECAs incorporate the Baltic Sea, the North Sea, the North American Emission control area (ECA) that broadens 200NM from the US and

Canadian coasts, and the US Caribbean ECA. The last two ECAs have likewise set limitations on PM and NOx emissions. The first results of the SECAs on emissions limitation show critical enhancements. In relevant literature, there has been no recent update on the portion of sea transport in SOx emissions, and the most recent solid estimate is in the previously mentioned investigation of Eyring et al., back in 2005. On a later publication, Zis and Psaraftis (2018) [6] utilized information from the Organisation for Economic Co-operation and Development (OECD) on its part nations and assessed those SOx emissions from all transportation modes represented 3.5% in 2015. Taking into account that road transport represented 0.48%, the portion of maritime transportation in SOx emissions has been radically diminished since 2005.

Notwithstanding the introduction of SECAs, as of January 2010 the European Union (EU) set a sulphur limit of 0.1% for ships berth in EU ports with stays longer than 2 h, as well as when sailing on inland waterways [7]. European Commission has advanced the further arrangement of shorepower to its part states through an authority suggestion [8]. Port authorities all throughout the planet have launched initiatives that advance utilization of low-sulfur fuel in their proximity, with the port of Singapore being a notable example under the Green Ship and Green Port programs offering monetary incentives for clean practices that reduce CO_2 and SOx emissions. At last, the ports of Los Angeles and of Long Beach have presented voluntary speed reduction programs (VSRP) in their proximity in return for a decrease of port disbursements accounts and are moving towards making the use of shorepower for ocean going ships mandatory.

Concerning guidelines focusing on sulfur outflows, ship owners can consent by one or the other changing to ultra-low sulphur fuels like Marine Gas Oil (MGO) or investing in scrubber systems that treat the exhaust gases to remove SOx and PM emissions hence permitting the utilization of Heavy Fuel Oil (HFO). Additionally, to adapt to guidelines on emissions at ports a vessel can either utilize cleaner fuel or, on the other hand, be retrofitted to get shorepower if the port has cold ironing facilities. Thusly, to address ecological regulation the shipowners have to pay to obtain abatement technology or increase their operating costs by utilizing cleaner yet more expensive fuel. Which option of the above mentioned is more cost-effective for the shipowner depends on various factors, including ship type, ship size, regulations affecting the waters in which the ship sails, and ports of call. Simultaneously, the choice of a port to put resources into innovations that permit the arrangement of shorepower relies upon a few variables, which stem from emissions decrease strategies, and the entrance pace of the innovation in the calling ships.

The last decades the demand of energy is being increased continuously. The massive use of different types of non-renewable sources of energy has led to very important problems in the earth, as global warming, by the production of big amounts of greenhouse gases (GHGs) [52]. Nitrogen oxides (NOx), carbon monoxide (CO) and carbon dioxide (CO2) are some of the elements that are being produced by the burning process of marine diesel engines and pollute the atmosphere. This fact is a result of the use of Heavy Fuel Oil (HFO) in vessels' engines which is preferred by the shipowners especially for economy reasons [53].

New technologies concerning alternative sources of energy have started to provide new environmental standards by reducing the emissions of harmful for the environment gases as CO_2. More than the 80% of the harmful emissions in the atmosphere are related to carbon [54]. Consequently, decarbonization constitutes on of the biggest environmental problems and despite the fact that the efficiency in terms of energy in the maritime transport has been increased significantly, shipping industry has the responsibility of almost 940 million tons of CO_2 emissions in the atmosphere per year. Taking into consideration the continuously increase of the global fleet we can easily understand that these emissions are going to reach a higher level in the next few years [55]. The use of alternative fuels seems to be the only solution for the environment and European Union has already include in her White Paper on Transport their introduction [56]. More specifically, in 2016, European Union has already released a «Strategy for liquefied natural gas and gas storage» in order to highlight the advantages and the potential of the use of LNG to all members of the Union. Moreover, in October 2014, the executive committee of the European Union obliged 139 ports in Europe to act appropriate in order to have the possibility to offer bunkering facilities for LNG until 2020 [59]. Additionally, the effort to control the pollution emissions was strengthen by the International Maritime Organization (IMO) through the introduction of new regulations. More specifically, International Convention for the Prevention of Pollution from Ships (MARPOL) was embraced by the IMO which also adopted amendments to MARPOL Annex VI (Resolution MEPC.203 (62)) through the introduction of an energy efficiency design index in order to reduce the CO_2 emissions [54, 61].

This paper discusses the possibility of different types of fuels or technological investments to be used as marine fuels from the perspective of shipowners, terminal operators, and regulatory bodies while considering the extent of ecological improvement that can provide. The first section of this paper presents a concise literature review of relevant research in port emissions as well as regulations that are used nowadays, which are imposed by the International Maritime Organization (IMO). The subsequent section presents an analysis and evaluation of different types of fuels which should appraise the new ecological equilibrium following the established environmental and safety regulations. In the last part, the benefits and drawbacks of its kind of fuel are widely expressed.

2. Environmental Assessment

Climate change and severe emission regulations in a great number of nations request fuel and engine specialists to investigate sustainable fuels and alternative sources of energy for internal combustion engines. Recently, it is projected that global energy demand has been expanded more and more in a daily basis. The increased amount of energy use produces a large amount of greenhouse gases (GHGs) by the consuming of petroleum products, which finally causes a worldwide temperature increase, so we face climate change. As of now, in industrial and transportation areas, diesel is chiefly utilized as petroleum derivative. Researchers as well as environmentalists all over the world are concerned about the way of eliminating this large amount of energy demand and at the same time, carbon dioxide (CO_2) emission reduction, which is one of the major components of GHGs [64,65]. In this respects, other sources of fuel may be a more sustainable alternative to ordinary fuels. Natural gas or petroleum gas can be produced from renewable sources, and as a result, it could be a source of feasible fuels. Moreover, it can be produced through the biomass conversion process (biomethane, which is otherwise called biogas, is a pipeline-quality gas produced using organic matter), better combustion efficiency, attractive cost, greenhouse gas minimization, which are the significant benefits as elective fuel [51]. Engine adjustment and legitimate use of LNG can essentially improve framework productivity and decrease greenhouse gas (GHG) emissions, which is amazingly useful to reasonable turn of events and lead to sustainable development. In addition, some significant ongoing investigations are additionally conducted in order to discover downsides, headway and future examination capability of the innovation. Vessels use diesel engines to consume fuel oil and heavy fuel oil (HFO) is ordinarily used as a marine fuel oil since it is cheaper than other fuel oil like marine gas oil (MGO). This fuel, with an average sulfur content of 0.1%, is a compliant fuel according to IMO's 2020 regulations [50]. However, air pollution and contamination from marine transport is an emerging issue for the environment and HFO has significant drawbacks of sulfur oxide (SOx) and nitrogen oxide (NOx) emissions [52]. The fuel that is most used by vessels is Heavy Fuel Oil (HFO, with an average sulphur content of 2.8%), which has the lowest price, but is the most harmful for the environment while emits the most pollutants compared to the other fuels. Nowadays, is compulsory for vessels using HFO to install scrubbers. So, their overall capital and operating cost rose [38].

2.1 Port emissions inventories

Davarzani et al. (2016) conducted a writing survey on greening ports and distinguish research regions for additional examination [9]. They note that the attention on emissions from ships and port equipment is relatively new with a huge expansion in distribution numbers during the last decade. Slow steaming has been analyzed and demonstrated to be a practical measure that at the same time diminishes carbon emissions [10]. The decrease of sailing speed in the full voyage also results in a little decrease of emissions in the proximity of the port [6]. Johnson and Styhre (2015) consider environmental advantages from diminishing port waiting times that would permit decreased sailing speeds at sea [11]. More recently, there has been a reemerge of sailing speed improvement issues especially given the necessity of vessels to change to low-sulfur fuel that is more costly. The research question of reducing sailing time within regulated waters has been figured by Fagerholt and Psaraftis (2015) as an optimization plan considers the ECA refraction problem [12]. Zis et al. (2015) propose a plan for the speed optimization issue that takes into consideration ECA and speed limitations close to ports, which for the first time considers the abated pollutants in the port proximity [6].

2.2 Emissions and Regulations

International Maritime Organization (IMO) introduced regulations and presented guidelines controlling specific pollution emissions. IMO adopted International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI in 1997, which began an effort to reduce SOx and NOx emissions from vessels that reduce ship emissions rates by 80% for both sulphur and nitrogen emissions worldwide, and greater than 90% reduction in IMO designated emissions control areas (ECAs) [52]. IMO continues staying focused on decreasing GHG emissions from international shipping and, as a matter of urgency, plans to eliminate them at the earliest opportunity in this century.

The IMO has a strategy which consolidates quantitative carbon intensity and GHG reduction targets for the international shipping sector, including:

1. A 40% reduction (at least) in carbon intensity by 2030 and making efforts in order to achieve a 70% reduction by 2050, both compared to 2008 levels.

2. Peak GHG emissions from international shipping as soon as possible and decrease them by at least 50% by 2050 compared to 2008 levels while making efforts towards phasing them out consistent with the Paris Agreement temperature goals.

3. MEPC comes along with new phases of EEDI.

Figure 1 shows CO_2 emissions from international shipping under this strategy and compared to one possible business-as-usual (BAU) emissions pathway. Emissions for the years 2007-2012 are from Smith et al., while emissions from 2013-2015 emissions are from Olmer, et al. Emissions in 2016 and beyond are projected using the ICCT’s fleet turnover model. The blue line in the figure is the minimum ambition of CO_2

reductions in the strategy; it reflects a 40% carbon intensity decrease by 2030 and a flat out of emissions of 50% by 2050, with full decarbonization by 2100. The green line shows the most extreme decrease desire in the strategy, driven basically by the objective of phasing out GHG emissions from international shipping at a pace consistent with the Paris temperature goals. The strategy implies cumulative CO_2 emissions of between 28 and 40 gigatonnes (Gt) from international shipping from 2015 through 2075, compared to a BAU emissions result of more than 100 Gt over the same period of time.

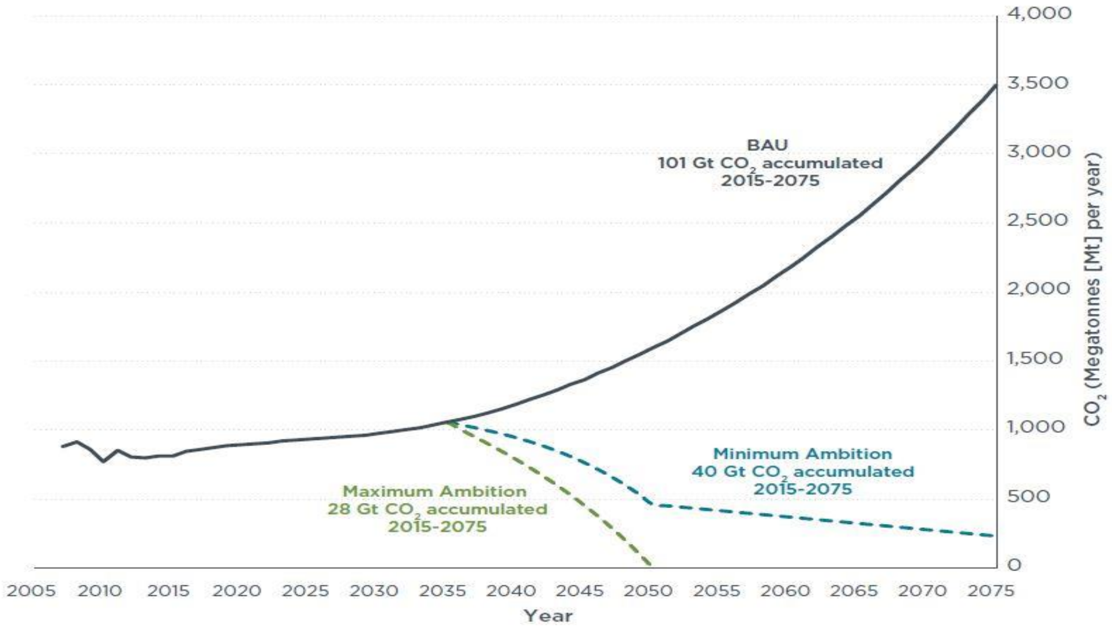


Figure 1: CO2 emissions from international shipping under IMO’s initial GHG strategy (blue and green) vs. BAU (black), with cumulative emissions 2015 through 2075. [133]

The fundamental benefits offered by LNG are higher safety, simpler transportation and capacity limit contrasted with CNG [14]. LNG is cleaner than coal and oil, therefore, it has a plenty of acknowledgment in the worldwide market [66]. Since LNG is clean, it is a promising option in contrast to diesel vehicles and is fit for repaying some of the extreme disadvantages of petroleum gas vehicles; for example, LNG fueled trucks have a higher reach (up to 700–1000 km) because of higher energy thickness [67]. In any case, while thinking about LNG as an alternative, the financial practicality should also be taken into consideration. The expense of a LNG fuel tank and the engine is roughly twice as high as a diesel [68].

2.3 The effect of EEDI and EEOI

The street towards the choice of a suitable Market Based Measure for worldwide transportation via vessels can be a long one. For now, maybe the most clearing piece of guideline that relates to GHGs and will affect vessel speed is the new adoption of the Energy Efficiency Design Index (EEDI) by the IMO. Surely, following quite a while of conversation and escalated and exceptionally political discussion among developed and developing nations, the finalization of the regulatory content on the Energy Efficiency Design Index (EEDI) for new ships was settled upon at the 62nd meeting of IMO's Marine Environment Protection Committee - MEPC 62 in July 2011 [87].

EEDI is given by a complex equation, of which the numerator is a component of all power generated by the vessel (main engine and auxiliaries), and the denominator is a result of the vessel’s deadweight (or payload) and the vessel's 'reference speed', characterized as the speed comparing to 75% of MCR, the maximum force of the ship's main engine. The units of EEDI are grams of CO2 per ton mile. The EEDI of a new building vessel is to be contrasted and the so-called "EEDI (reference line)," which is characterized as EEDI (reference line) = aDWT-c, where DWT is the extra weight of the vessel and an and c are positive coefficients determined by relapse from the world fleet data base, per major vessel category [87].

For a given vessel, the achieved EEDI value ought to be equivalent or less than the necessary EEDI value which is given by the following equation.

Achieved EEDI $\leq$ Required EEDI = (1-X/100) aDWT-c (3)

where X is a "decrease factor" determined for the required EEDI contrasted with the EEDI Reference line (The values of X specified by the IMO are 0% for ships built from 2013-2015, 10% for ships built from 2016-2020, 20% for ships built from 2020-2025 and 30% for ships built from 2025-2030. This means that it will be more stringent to be EEDI compliant in the years ahead). The reference line boundaries an and c in (3) have been finalized by regression analysis after a long discussion inside the IMO. It is intriguing to mention that Ro/Ro vessels are so far excluded from EEDI, because of the fact that no sufficient regression coefficients have been acquired for this class of vessels.

It tends to be seen that EEDI compliance effectively imposes a limit on a vessel's design speed, as the left-hand side of inequality (3) is a polynomial function of the designed speed though the right-hand side is autonomous of speed. In this way, though the genuine objective of EEDI is to design vessels with better hull, machinery and propellers to be more energy efficient, a simple solution may be to decrease design speed, and, as an outcome, installed power. This might have negative consequences on shipping wellbeing and safety. It might likewise affect on total CO_2 emitted, as an underpowered vessel would consume more fuel and subsequently emit more CO_2 at the same exactly speed, especially in the event that it attempts to keep up with speed in bad weather conditions [88].

That effect on ship speeds notwithstanding, EEDI, being a design index, will influence speeds just at the strategic level and cannot catch the impact of slow steaming. In that way, freight rate and bunker price variances over a vessel's life cycle are effectively ignored by EEDI. Indeed, an EEDI-compliant vessel would have no incentive to slow steam if the market were down, and an underpowered vessel would consume more fuel whenever instigated to speed up in boom market periods [112].

What might be compared to EEDI is EEOI, the "Energy Efficiency Operational Indicator." EEOI utilizes a comparative equation to EEDI, the difference being that all factors take on their functional as opposed to configuration esteems. This would incorporate utilizing the vessel's real payload rather than the deadweight, and the real operational speed rather than the design speed. Use of EEOI is anticipated inside IMO's Ship Energy Efficiency Management Plan (SEEMP), which was also adopted in July 2011. Albeit maybe the reasoning of utilizing a particularly functional file can be advanced, concerns have been communicated on the usefulness of EEOI. These have been widely expressed on the ground of pragmatic execution; however, a similarly significant issue is if EEOI misleadingly imposes a functional speed limit in boom periods. If this is the case, significant distortions and costs might happen. Apparently, a Market Based Measure, for example, a levy would be a more efficient approach to induce slow steaming and lessen emissions, and the models developed here could be utilized to assess the effect of such a measure.

In all cases, newbuild ships entering the fleet will comply with the relevant design efficiency requirements (EEDI) after some time, for the given vessel type and size. These are known today and become more onerous within a specific time period (in all situations 10%, 20% and 30% improvement by 2015, 2020 and 2025 separately).

The guidelines just set a minimum compliance prerequisite. In any case, fuel change (to lower carbon factor), plan speed reduction or innovations may result in an EEDI lower than regulated, which, also, turns out to be beneficial at guaranteed time-step. In this situation, this is chosen as the newbuild vessel's particulars.

Subsequently, sometimes, the EEDI pattern of the newbuild ships may increase over time, for instance because that specific cost, market and regulation scenery in a later time-step finds a profit maximizing solution that stays compliant with the minimum EEDI guideline yet brings about a higher emission level. This does not mean non-compliance (EEDI will still be equivalent to the regulatory level).

It must be noticed that the EEDI boundary is only a method to emphasize at the developing technical specification of the fleet. The actual energy demand and emissions of the fleet are a function of functional parameters, and as functional speed leave altogether from design speeds EEDI will turn out to be increasingly misrepresentative (this is regularly seen in the scenario results, with older and less technology advanced vessels operating at lower speeds to remain competitive in an environment of higher fuel prices).

It would be ideal if we made an attempt to envision the unpredictable and complex interactions between transport demand, speed, EEDI and fuel, innovation technology and machinery combinations.

2.4 Existing natural effect of shipping in NA ECA

Vessels are huge contributors of the US and Canadian mobile-source emission inventories. The ships produce huge emissions of fine particulate matter (PM2.5), NOx and SOx that add to poor air quality. Emissions to the air from ships cause harm to general wellbeing, contribute to visibility impairment and, moreover, have other negative ecological effects.

Some of the USA's most serious ozone and PM2.5 non-attainment regions are influenced by emissions from vessels. Right now, more than 30 significant US ports along the Atlantic, Gulf of Mexico and Pacific coasts are found in non-attainment regions for ozone as well as PM2.5.

Air pollution from ships is relied upon to developments throughout the following twenty years. With no of the arranged emission control methodologies, by 2030, NOx emissions from vessels would be projected to dramatically increase to more than double maybe, growing to 2.1 million tons every year while yearly PM2.5 emissions would be relied upon to increase significantly to 170,000 tons. The North American ECA guarantees that emissions from vessels will be decreased altogether, creating important advantages to enormous segments of the population, as well as to marine and earthbound environments.

2.5 Gas engine emissions

The principal sorts of emissions from the combustion process in an interior combustion are CO_2, NOx, SOx and PM (particulate matter). The amount relies upon the kind of fuel and the combustion cycle. CO_2 is an ozone harming gas that is among those responsible for global warming. NOx is formed because of high temperature and pressure during the combustion process and contributes to the formation of smog as well as contributing to the creation and formation of ground level ozone. SOx cause acid rain and have adverse effects on general wellbeing. The emission amount is straightforwardly related to the amount of sulfur present in the fuel.

Moreover, SOx and NOx add to PM formation results through a series of chemical and physical reactions bringing about sulfate and nitrate PM. PM and black carbon are other strong pollutants made from the combustion cycle. PM results from different contaminations and incomplete combustion processes. Most PM emissions are harmful to people and may have contributing factors to global warming. The gathering of dark carbon on glacial masses and polar icecaps might accelerate the melting rate by increasing the focus of daylight (United States Environmental Protection Agency, 2010). There is an increasing focus on dark carbon emissions and its effect on climate and its commitment to global warming.

Unlike the limits in North America imposed by authorities on land-based transport, power generation and inland waterways, there are presently no restrictions indicated by IMO on emissions of Unburned Hydrocarbons (HC) or Carbon Monoxide (CO). The justification of this is the fact that it is considered to be basically that these are not the critical emission parts from a well-maintained diesel motor when working under marine transit conditions. In the USA, the EPA have specified HC and CO limits for all engines, including the biggest marine models.

In case of gas engines, they have higher emissions of CO and HC than diesel engines. While guidelines are generally set up for these mixtures in the commercial marine area, this is most likely an aftereffect of the modest number of engines. If Natural Gas engines become the more widely utilized, CO and HC limits may be anticipated. There are treatment strategies for lessening emissions of CO and HC in engine exhaust gas.

2.5.1 Greenhouse gases (CO2, CH4)

CO_2 emissions are related to the carbon content of fuel and the amount of fuel burned-through. The CO_2 emissions can be decreased by a further developed fuel efficiency or by improvement in the vessel overall plan, design and operating effectiveness (trim management, route choice, reducing speed or using eco-speed, further development of vessel’s structures, etc.)

The natural gas fueled marine engines presently being used on the current gas fueled vessels in operation are medium speed, Otto cycle engines, either spark ignition or pilot fuel injection. Gas engines working on the diesel cycle are likewise accessible, both as four stroke medium speed and two stroke low speed engines.

Notwithstanding the working cycle, strategy of natural gas ignition (flash ignited or diesel pilot), or the engine operating speed, utilizing natural gas instead of fuel oils brings about a decrease in the measure of CO_2 created by the actual engine because of the lower carbon content.

This decrease in CO_2 production might be to some degree offset by methane slip, the term to depict the fraction of natural gas that passes through the motor without burning. Methane slip is more prevalent in engines working on the Otto cycle. The amount of methane released by natural gas engines working on the diesel cycle is practically identical to procedure on conventional liquid fuel. Makers of Otto cycle natural gas engines are proceeding to make advances in decreasing the amount of methane slip by utilizing a lean burn rule. There is the possibility to diminish methane emissions because of the enhanced engine design, combination of methane related controls, and the use of methane-designated oxidation catalysts.

Nonetheless, the absolute GHG emissions from the 'well' to 'propeller' utilizing natural gas are standing out enough to be noticed, and as current research shows the LNG pathway will impact the actual advantages when contrasted with regular fuel [107]. Use of best practices in the LNG supply chain can lessen the amount of methane released to the atmosphere.

2.5.2 SOx emissions

The amount of SOx produced relies upon the sulfur content of the fuel. There are tiny amounts of sulfur in the natural gas produced in North America. Along these lines, when compared to other ordinary diesel fuels with sulfur content equivalent to IMO limits, the amount of SOx is highly diminished.

While diesel ignition double fuel or direct injection natural gas engines may conceivably use higher sulfur content fuel oils for pilot fuel, the SOx emissions from these sorts of engines are the sum of the contributions from the natural gas and pilot fuel. There are negligible SOx emissions for a spark-ignited off Otto cycle engine operating on gas as it were. There may be some limited quantities in view of ignition of the lubricating oils.

2.5.3 NOx emissions

NOx forms during ignition and is principally a function of the temperature in the combustion zone. In a diesel cycle engine, there is a fire front where the temperatures are exceptionally high, and this structures NOx. In general, the higher the temperature, the more NOx is produced. In any case, the formation of NOx is a perplexing issue, and a few formation systems are significant. Additionally, it is reliant upon the amount of excess air during the ignition process.

Diesel cycle engines, whether or not they are fueled by natural gas or by fuel oils, have higher NOx emissions contrasted with engines working on the Otto cycle.

In case of gas fueled engines working on the diesel cycle, SCR or EGR might be needed in order to follow the IMO Tier III NOx limits, albeit the particular emissions management strategy will change depending on the engine producer.

In case of gas fueled marine engines working on the Otto cycle, neither SCR nor EGR are needed to comply while operating on gas only. In any case, in case of dual fuel engines while operating on diesel engines, SCR or EGR will be needed to conform to NOx III limits.

2.5.4 PM emissions

PM emissions can be credited to fragmented burning of fuels. High cylinder temperatures and pressing factors can cause a portion of the fuel injected into a cylinder to break down rather than combust with the air in the cylinder space. This breakdown of the fuel can lead to carbon particles, sulfates and nitrate aerosols being created. Fuels with higher sulfur content, result in higher PM emissions since a portion of the fuel is converted to sulfate particulates in the exhaust. Nonetheless, sulfur is not the only source of particulate matter. According to a new study [6] natural gas PM emissions are diminished by approximately 85%.

2.5.5 Effect on climate

As a result of the ECA and the more severe emission prerequisites for marine engines, vessel will diminish their emissions of nitrogen oxides (NOx), sulfur oxides (SOx) and fine particulate matter (PM2.5). In 2030, as indicated by EPA, emissions from these ships operating in the ECA are expected to be diminished every year by 1,300,000 tons for SOx, 1,200,000 tons for NO x and 143,000 for PM (2.5). The advantages are expected to incorporate include between 12,000 to 31,000 unexpected losses (premature deaths) and relieving respiratory side effects for almost 5,000,000 individuals every year in the US and Canada. The adapted health-related advantages are assessed to be somewhere in the range of $110 and $270 billion in the US in 2030.

In view of EPA investigation, the US coastline [98], and a large part of the interior of the nation will encounter critical improvements in air quality because of decreased PM and ozone from ships following ECA guidelines. Coastal regions will experience the biggest enhancements; notwithstanding, critical upgrades will stretch out far inland.

3.Entering speed limitations – slow steaming application

A related policy issue is that commanding direct speed limits. If emissions can be minimized by decreasing pace of the vessel, would someone be able to accomplish this desirable result by forcing speed limits? This is an argument that is heard very often nowadays. Among different lobbying groups, the Clean Shipping Coalition (CSC), a Non-Governmental Organization, advocated at IMO/MEPC 61 that "*speed reduction ought to be pursued as a regulatory choice by its own right and not only just as potential outcomes of market-based instruments or the EEDI.*" However, that proposition was dismissed by the IMO. Notwithstanding this choice, lobbying for speed limits has proceeded by CSC and different groups. Recipients of this lobbying activity have incorporated the IMO and the European Commission [90].

Our own situation on this issue is not in favor of speed limits. It is completely clear that slow steaming and speed limits are two different things, as the first is a willful reaction and the second is a mandatory measure. If the speed limit is over the ideal speed that is voluntarily chosen, then, at that point it is unnecessary. If it is below, it will cause (maybe huge) distortions in the market, especially in bloom periods, and costs that might surpass the advantages of speed decrease [92]. Possible side-effects include, among others, building more ships to match with demand, with possible increase of emissions during shipbuilding and recycling, increasing cargo inventory costs, producing more GHGs if low-powered vessels are compelled to speed up in bloom periods, and having adverse implications on ship safety [89]. There is no thorough examination of the conceivable market distortions of a speed limit [91].

4. LNG

4.1 Properties of LNG

Maritime industry is expected to increase the use of LNG as a marine fuel in the near future [56]. Between different kind of fuels, natural gas is considered to be one of the most significant alternative sources of energy for the humanity [62]. More specifically, the use of Liquefied Natural Gas (LNG) as a fuel is considered to be one of the most promising energy solutions for the future [53]. Comparing the different alternatives of fuels, the transportation sector tends to prefer the use of natural gas [60]. Taking into consideration the technoeconomic effectiveness of energy sources for long-range use such as LNG and CNG and their effect to the environment, previous studies have proven that Liquid Natural Gas is definitely the most sustainable [60]. Safety, storage and easy transportation empowers these studies [60]. Until now, LNG used to be preferred not by the maritime industry as an alternative fuel but for different purposes as the production of electricity especially for safety reasons [52]. However, many shipowners have started to investigate precisely alternative sources of energy in economic terms. There is a tendency to leave heavy fuel oil (HFO) to low sulphur fuel such as marine gas oil (MGO), ultra-low sulphur fuel (ULSFO), maritime diesel oil (MDO) and alternative fuel as Liquid Natural Gas (LNG). One of the basic reasons that the LNG seems to be attractive to the shipowners is low costs of bunkering [58].

LNG is a relatively cleaner energy than HFO and MDO that emits much less SO_2 and NOx but more CH_4 [40]. It is a combination of gases, and its liquefaction is finished by diminishing the temperature underneath the boiling point. The amount of methane in LNG is about 87–99 mole%, and the excess portion is propane, ethane and 19 other heavier hydrocarbons depending on different LNG sources [69, 70]. For example, the LNG imported from Belgium contains 90% (by mass) methane and 10% (by mass) ethane [71]. The lower calorific value of LNG is 21 MJ/L, and the higher calorific value is 24 MJ/L at -164 C degrees [72]. To produce LNG, natural gas is refrigerated at -162 C degrees at atmospheric pressure; hence, LNG is known as a cryogenic fluid [73, 74]. During liquefaction of natural gas, the primary component, i.e., methane, is cooled underneath its boiling point. Simultaneously, the concentrations of oxygen, carbon dioxide, water, hydrocarbons, and some sulphur compounds are either taken out or decreased in some small extent [75]. At atmospheric conditions, to produce equal energy, natural gas requires 600 times larger volume compared to LNG [76]. Besides, both LNG and its vapor will not cause fire or explode when exposed to the unconfined environment [77]. LNG is a non-toxic, non-corrosive, colorless, odorless, safe and clean type of natural gas [78, 82]. LNG isn't dangerous; along these lines, to ignited, first, it must be disintegrated and afterward blended in with air at a proper portion [36]. Moreover, the existence cycle CO_2 emissions of LNG are 18% not as much as its counterpart gasoline vehicle model [86]. These benefits empower LNG as a likely fuel for the transportation area.

Natural gas resources are developing in different countries of the world, especially in the United States, a fact that create expectations for a decrease in the LNG prices in the future [59]. Except of the low prices, the combination of an environmentally and technically friendly fuel empowers the attractiveness of the LNG to the shipowners [58]. Technology concerning Liquefied natural gas (LNG) is developing quite fast, as its ability to be produced from renewable sources is a major advantage [52]. Moreover, in contrast with other alternative sources of energy, LNG can replace older types of fuels in long – distance transport as the maritime [56]. Additionally, several research has shown that the use of LNG as fuel improves the combustion efficiency and restricts the greenhouse gas emissions [60]. Combusting Liquid Natural Gas, except of lower emissions of Particulate Matter (PM), produces no sulfur oxides (Sox) emissions as it does not contain any sulfur. LNG combustion also produces lower carbon emissions in comparison with marine gas oil (MGO) and heavy fuel oil (HFO) burning process [57]. Vessels which consume LNG instead of HFO have as a result emissions reduction such as 85-95% of NOx and 20% of CO_2 [59]. Due to the major environmental advantages of the LNG as fuel and the new regulations in the shipping industry, the number of the vessels that use LNG as a fuel is increased and by the 2025 these vessels are predicted to be 700 in the whole world [55].

Additionally, LNG is more efficient and attainable for transportation contrasted with pipeline gases [72,78,79]. Well purified and condensed LNG can be effectively shipped over the ocean [80]. While shipping, to handle the low temperature of LNG, specifically designed double-hulled ships are used [71]. During combustion, LNG has almost no SO_2 and particulate matter emission [85]. LNG is non-combustible; hence, the actual fluid will not burn. However, the vapor of LNG causes flash fire because it is highly flammable with air. The flashpoint of LNG is -187.8 C degrees, however, the autoignition temperature is 537 C degrees [83]. Thermal shield, which is required as well as lower density of LNG compared to heavy fuel oil (HFO), make the fuel tank required for LNG is 2.5–3 times bigger than an HFO tank [84]. Nevertheless, in the LNG transportation area, there are some possibilities of accident, for instance, the spillage of LNG into ground and ocean, and rollover of the LNG tank [80]. However, LNG vapor only burns when it is mixed in a concentration of 5%–15% with air [75, 78]. All these factors show that LNG is of utmost importance on the grounds that is a safe alternative fuel for the transportation sector.

4.2 Environmental studies on feasibility and use of LNG as fuel [106]

The ecological advantages of using LNG as fuel are huge. Contrasted with the use of diesel fuel, utilizing LNG will lessen the NOx emission by approximately 90% on a lean consume gas fueled motor, and the SOx and particulate matters emissions are negligible without the need of any minimization technologies. The CO_2 emissions are about 20% lower contrasted with diesel fuel on account of the lower carbon content. Be that as it may, the overall impact on GHG (Green House Gas) emissions needs further examination and studies.

4.3 Safety of LNG [113]

The properties of LNG are portrayed in Appendix B, including the hazards and safety issues involved in dealing with natural gas and LNG. The principal safety difficulties of using LNG as a fuel are described below.

First and foremost, fire and blast hazards as well as flammable in scope of 5% to 15% mixture in air. Moreover, natural gas is odor and colorless so it can cause fire and explosion without anyone noticing it.

Low temperature of fluid gas/cold jets from compressed natural gas – LNG at - 163°C can produce serious injuries. Furthermore, normal ship steel will be weak and can break if it is exposed to LNG.

Gas tank enormous energy content is of utmost hazard too on the grounds that protection is needed from transport side and base (impact and establishing). Additionally, protection from outside fire and BLEVE (boiling liquid expanding vapour explosion) should be taken into serious consideration, as well as protection from mechanical impacts.

The IMO Interim Guidelines and the forthcoming IGF Code [97] are centered around indicating the boundaries required in order to decrease the degree of hazard by specifying the prerequisite for the design of the LNG fueled ships and the onboard system.

The improvement depends on the experience acquired from the existing gas carriers and the vessels of LNG fueled ships that have been fabricated and are in operation.

5.Hydrogen

5.1 Introduction

Hydrogen is regularly found naturally as a compound of either water or methane. To acquire pure hydrogen, the element should be isolated from these mixtures. At standard conditions, hydrogen is an odorless, tasteless, colorless, non-harmful, somewhat nonreactive, and highly ignitable gas with a wide flammability range.

Hydrogen is usually delivered by changing over petroleum gas or coal into hydrogen gas and CO_2, despite the fact that for the long-term supportability objectives, environmentally friendly power can be utilized to create hydrogen through electrolysis. In manufacturing, hydrogen is regularly used for chemical production or as an industrial feedstock [94].

Lately, industry has perceived hydrogen's capability to produce power through fuel cells and combustion technologies. While in many cases hydrogen might be delivered locally from fuel reforming of a hydrogen carrier (and thus may have direct GHG emissions), in a hydrogen fuel cell consuming a pure hydrogen fuel supply, greenhouse gases are not transmitted. In burning engines or gas turbines, hydrogen can be utilized to essentially lessen GHG emissions. Note that gas turbines consuming hydrogen (or hydrogen mixes with natural gas) are used essentially for land-based power production and are not considered in this record for power generation on marine vessels [93].

While hydrogen seems, by all accounts, to be an optimal fuel for power generation, it carries different difficulties of advanced storage requirements and fire hazard alleviation. To turn into a serious elective marine fuel, hydrogen may also confront the challenges of accessibility and significant expenses to scale production and transportation infrastructure [95,96].

5.2 Hydrogen as fuel for the reduction of greenhouse gas

Its low density makes any hydrogen disperse relative quickly when released in an open environment. Hydrogen in the air cannot be contained by earth's gravity and ultimately escapes into space. Hydrogen leaks are thought to be non-harmful, albeit the wide flammability range and potential for combustion can raise worries of hydrogen safety and risk management onboard. These concerns are addressed in the hydrogen safety and design consideration sections.

Hydrogen can possibly be a zero-carbon marine fuel when it is consumed in a fuel cell or a mono-fuel internal combustion engine. When consumed in a dual combustion engine, hydrogen can fundamentally minimize carbon emissions. Hydrogen is characterized by having an exceptionally low tank-to-wake (TTW) emissions impact, which considers the emissions produced by an energy source. However, the life cycle of hydrogen production should be considered to assess the general emissions of GHG from hydrogen [114].

At the point when non-renewable energy sources and fossil fuels are used to create hydrogen, carbon and GHG emissions may not really be decreased. Well-to-tank

(WTT) emissions consider all pollutants created during fuel production, storage, and transportation until the end consumer. These can incorporate the emissions created when coal or natural gas is processed to produce hydrogen, or the fossil fuels combusted to create grid electricity used to produce hydrogen through electrolysis. To completely minimize and eliminate hydrogen emissions before fuel delivery, it is of utmost importance to focus on carbon-free production, storage, and transportation strategies [115].

Hydrogen can be created in renewable or 'green' ways that can take out upstream carbon and GHG emissions and result in exceptionally low WTT outflows. When both WTT and TTW emissions are minimized from the fuel life cycle, a zero-carbon well-to-wake (WTW) fuel choice is made. Sustainability check plans or certifications and verifications of origin (GO) certificates, for example, the EU CertifHy task can be used, which might be carried out in the hydrogen market to track and evaluate the emissions footprint of generated hydrogen. Such plans might be executed provincially or nationally but are not yet mandated by the IMO [116].

5.3 Hydrogen as marine fuel

Hydrogen is described by having the most significant and the highest energy content per mass of all chemical fuels at 120.2 MJ/kg, as shown in Table 1 contrasted with other marine fuels. In terms of mass energy, it surpasses MGO by 2.8 times, and alcohols by five to six times. Consequently, hydrogen fuel can increase the powerful effectiveness of an engine and assist with diminishing specific fuel consumption. Nonetheless, on a volumetric premise, because of its lower volumetric energy density, fluid hydrogen might require four times more space than MGO or around two times more space than liquified petroleum gas (LNG) for a same measure of carried energy.

Moreover, critical to think about when contrasting fuel energy and required volumes are the energy efficiencies of the final buyer, or electrical energy losses in fuel cells. Valid for every single marine fuel, extra volumes of fuel might be needed to account for effective losses between the tank to the output shaft power. Hydrogen requires low temperatures underneath - 253° C (- 423.4° F) to liquify. Because of this exceptionally low temperature, the necessary volume to store fluid hydrogen could be significantly higher while considering the fundamental layers of materials or vacuum insulation for cryogenic storage and other underlying structural arrangements [99].

	UNIT	HYDROGEN	MGO	HFO	LNG	ETHANE	METHANOL	ETHANOL	AMMONIA
Boiling Point	° C	-253	180-360	-161	-89	-43	65	78	-33
Density	kg/m3	70.8	900	991	430	570	790	790	696
Lower Heating Value	MJ/kg	120.2	42.7	40.2	48	47.8	19.9	26.8	22.5
Auto Ignition Temp	° C	585	250	250	537	515	450	420	630
Flashpoint	° C	-	>60	>60	-188	-135	11	16	132
Energy Density Liquid (H2 Gas at 700 bar)	MJ/L	8.51	38.4	39.8	20.6	27.2	15.7	21.2	15.7
Compared Volume to MGO (H2 Gas at 700 bar)		4.51 (7.98)	1.00	0.96	1.86	1.41	2.45	1.81	2.45

Table 1: Properties of Hydrogen Compared to Other Marine Fuels

Hydrogen can likewise be stored inside different materials, such as metal hydrides. This storage technique binds hydrogen to metal combinations in porous and loose form by applying moderate pressure and heat. Hence, hydrogen is extracted by eliminating the pressure and heat. While technologically feasible and safe, metal hydride and other hydrogen storage techniques inside solid materials may not be a weight-effective answer for hydrogen storage on board ships, and this idea is not addressed further in this whitepaper.

Because of the difficulties identified with low temperature or high-pressure storage, hydrogen can on the other hand be carried inside different substances like ammonia or methanol. These fuels might require less energy than that needed to refrigerate liquified hydrogen or to compress gaseous hydrogen. Some fuel cells can consume ammonia, methanol or other hydrogen carrier fuels by reforming and separating hydrogen from the fuel utilizing internal reformers. Nonetheless, these innovations may require higher energy input to hydrogenate and change the fuel, which subsequently may result in less efficient electrical creation than pure hydrogen containment and consumption in fuel cells. Ammonia as an energy carrier can take place in the life pattern of hydrogen fuel, leading to either consumption in a fuel cell or combustion engine [100].

Hydrogen and hydrogen containing fuels are regularly consumed in fuel cells to produce zero-emissions TTW electricity, regardless of how the hydrogen was produced. There are many finished and progressing investigations and studies on fuel cells, basically to assess and further develop fuel cell energy productivity. There are a few kinds of fuel cells with different functional and cost trade-offs, including alkaline or SOFC, yet, as a general rule, they consume hydrogen and oxygen and generate heat, water, and electricity.

Hydrogen fuel blends consist of hydrogen mixed with a compatible fuel. The most widely recognized are hydrogen and LNG (HLNG) blends which can lessen exhaust gas emissions and GHG footprint. A hydrogen-cryogenic natural gas (HCNG) blend can normally be made of a blend of 20% hydrogen and 80 percent compressed natural gas. Hydrogen blends with flammable gas are probably going to be adopted for power generation ashore in gas turbines and are not the focus of this whitepaper.

Hydrogen may also be co-combusted with diesel fuel, and depending on the proportions utilized, reductions of nitrogen oxide (NOx) emissions might require the utilization of exhaust gas aftertreatment technologies. Other minor changes in engine planning and control frameworks might be needed to accomplish ideal engine performance.

5.4 Safety of Hydrogen

5.4.1 Characteristics of hydrogen

Hydrogen is a remarkable basic substance with a few significant physical and synthetic attributes. Some of the properties of hydrogen are recorded in Table 1 contrasted with methane, the main component of LNG, and the practically identical properties of the common marine fuel MGO.

The most significant safety worries for hydrogen are its flammable properties and wide combustibility range, as displayed in Figure 2. The combustibility range increases when blended in with pure oxygen.

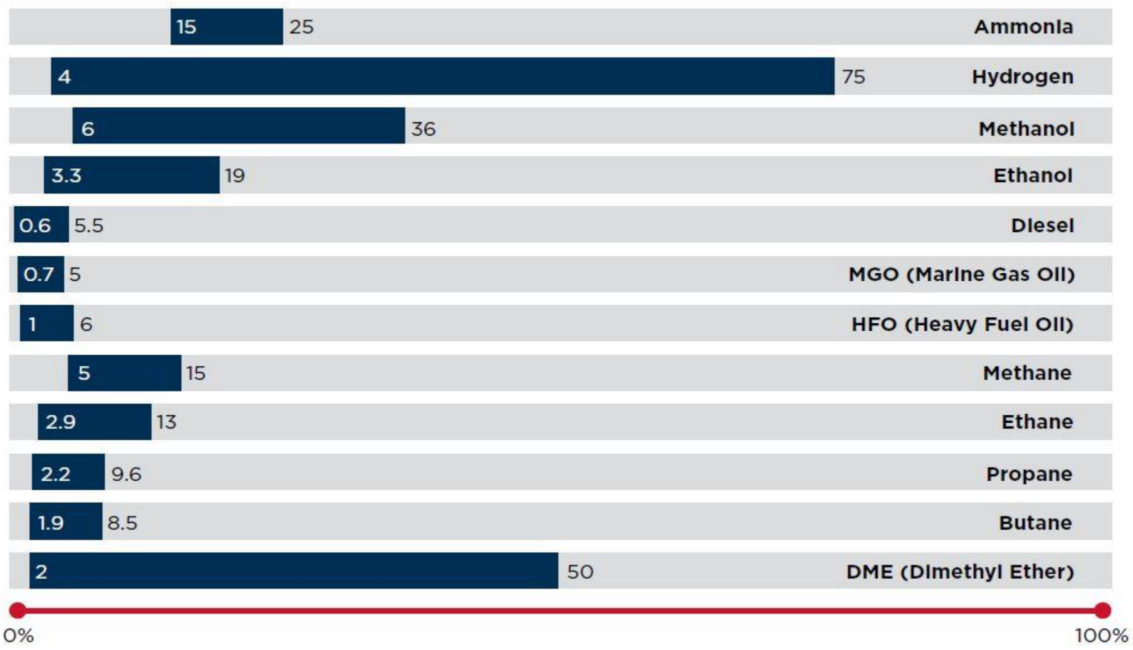


Figure 2: Typical Gas Flammability Ranges in % Volume with Air [132]

While hydrogen leaks in open areas are relied upon to disperse rapidly, any leak in open or contained spaces can be a very serious fire peril because of the fast formation of flammable gas mixture. More is discussed about hydrogen leaks, fire prevention and leak detention and anticipation in the fire safety section.

Hydrogen is a gas or cryogenic fluid and has one of the lowest melting and boiling points of all the elements aside from helium. To acquire fluid hydrogen, the fuel should be stored at temperatures underneath - 253° C (- 423.4° F), which can require high energy input. At this temperature, other common gases or compounds can liquify or solidify on contact and ought to be separated from liquified or cryogenic hydrogen. Human contact with cryogenic materials or uninsulated tanks, lines or valves can cause cold burns or serious skin damage and traumas. Albeit non-poisonous and non-toxic, at high concentrations hydrogen can act as an asphyxiant while displacing accessible oxygen [117].

5.4.2 Fire safety

Hydrogen is a flammable gas because of its extremely low activation and ignition energy. Notwithstanding this, the dangers of hydrogen explosions can be minimized and mitigated if appropriate measures and protocols are seriously taken into consideration and followed [118].

The flow or agitation of hydrogen gas or liquid can make electrostatic charges that can bring about sparkles and start of ignition of flammable concentrations of hydrogen. Therefore, ensuring that all hydrogen is being taking care of handling equipment is protected from electric charge build up and potential sparks in order to avoid hydrogen ignition.

Hydrogen flames are hardly detectable, consuming mostly outside of the visible light spectrum, and can be extremely challenging to distinguish. Additionally, hydrogen burns very quickly contrasted with other combustible compounds, with a maximum speed of 3.15 m/s. Contingent upon the flammable conditions, pressure and concentration of hydrogen, a blend exposed to ignition sources might combust by either deflagration (subsonic combustion) or explosion (supersonic combustion, which cannot happen in open air outdoors). Hydrogen gas systems, on the one hand, should account for securities against deflagrations engendering through the piping and containment systems utilizing appropriate pressure relief systems, rupture disks or relief panels. On the other hand, explosions can bring about outrageous pressure increases (up to 20 times air pressures) and are more difficult and challenging to contain than deflagrations. The best practices to alleviate the dangers and minimize the risk of deflagrations and explosions are to eliminate the potential outcomes of hazardous concentrations of hydrogen by using appropriate gas management, pipe purging and ventilation practices or VECS system.

Contained regions are particularly susceptible to fire perils if hydrogen leaks inside. Essential security measures when considering carrying and utilizing hydrogen incorporate legitimate ventilation, hydrogen gas detection, and properly rated electrical equipment in dangerous areas and enclosed spaces into which hydrogen might leak and build to levels that may cause combustible and flammable conditions.

The development and probability of combustible hydrogen and air mixtures relies upon the concentration of hydrogen, storage pressures (i.e., the speed of jet from a leak), the amount of stored hydrogen, the amount of insulation, the area of release and the weather conditions (like breeze, air, temperature, heat, etc.)

In the event of utilizing gaseous hydrogen as a fuel, compounds that are normally added to flammable gases to distinguish leaks should not be used as the sulfur in those mixtures can respond with and degrade hydrogen. Dedicated hydrogen sensors might be very useful when using vaporous hydrogen, yet may not be practicable, for instance, in areas of high transient airflows where escaping gas may unintentionally be directed away from sensors. In that way, it is also desirable to implement leak identification and detection procedures and strategies in the actual equipment, for example observing pressures under conditions of no gas flow and confirming those boundaries indicate the absence of leaks.

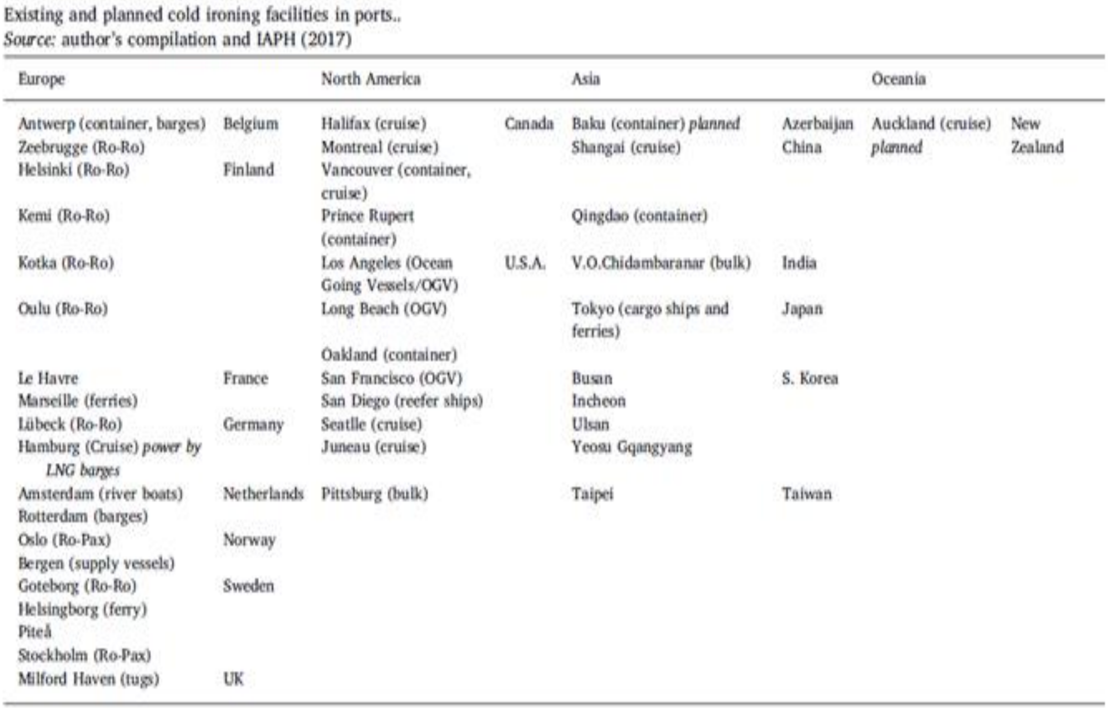
To smother a hydrogen fire, dry chemical extinguishers or carbon dioxide extinguishers can be utilized. In the event that a hydrogen fire spreads to other materials around or close to contained hydrogen in lines or tanks, proper water spray cooling and insulation arrangements ought to be set up to shield and protect the contained hydrogen from heating up, and pressure alleviation arrangements should be set up to protect from over-pressurization. Both protective measures can mitigate the dangers and risks of gaseous hydrogen reaching the explosive temperature limit within containment or of a fluid hydrogen boiling liquid expanding vapor explosion (BLEVE).

5. Cold ironing

6.1 Authentic outline of cold ironing and its current status worldwide

The term cold ironing is credited to the act of cooling down of the iron coal-fired engines while the vessel was tied to the port previously. Ships can utilize CI either from ship to ship (military applications) or from shore to ship with the last having environmental advantages. The benefits are transcendently nearby as the vessels' channels don't deliver pollutants in port. Despite what is generally expected, the energy demand of the ship is met by the power plant (or other kind of source) that provides current to the port. As a result, with the utilization of CI locally there are decreased vessel’s emissions (boilers will be working and will still emitting at berth). Universally, it will rely upon the beginning of the energy giving the shorepower (with increased emissions locally close to the power provider). The environmental trade-offs arising from CI have been examined in a progression of applied contextual analysis for ports with different characteristics (visiting ships, size, type) in different places of the world [13]. Tseng and Pilcher (2015) consider the capability of shore power in the port of Kaohsiung and gauge the natural advantages that would bring for various quantities of ships utilizing the innovation [15]. They additionally furnish subjective experiences dependent on interviews with port administrators. On the technological side of CI, Sciberras et al. (2015) investigated the impacts of such electrical systems (how other customers powered by the grid are affected) and the nature of the conveyed power to the vessel [16]. Prousalidis et al. (2014) thought about joining CI with smart grids and proposed playing out a money saving investigation of CI as an emission decrease innovation dependent upon the situation [17]. Innes and Monios (2018) consider the financial plausibility of CI establishments at more modest or medium size ports and examine the offshore supply vessel port of Aberdeen. They ascertain yearly emission savings and track down that under specific presumptions the external cost saving advantages would have a pay-back period of seven years with no other subsidies [18].

In this segment a sum of ports all throughout the planet that as of now give or have chosen to invest in shore power is introduced. In California, six ports are influenced by the at-berth guidelines; the ports of Los Angeles (POLA), Long Beach (POLB), Oakland, San Diego, San Francisco, and Hueneme [19]. In Europe, one of the principal executions of CI was dispatched in Sweden. The Port of Gothenburg has two passenger and Roll-on/Roll-off (Ro-Ro) ship terminals furnished with electric associations for CI. Vessels staying at the terminals have allocated areas and run on ordinary planned routes. Shore-power is provided by nearby excess wind produced power and is hence promoted as substituting fuel for renewable fuel sources (RES). It must be noticed that ships have a low hoteling power demand: the ships get shore power just for lighting and ventilation use. Furthermore, ships have no cargo moving machinery and have little dockside activities. Subsequently, the Gothenburg electrification process is a lot less complex than OGVs that are the objective in Californian ports. The port authority estimates a decrease of 80 metric tons NOx, 60 metric tons SOx and 2 metric tons PM each year for the six week by week transports calling and utilizing the installation. Terminal operators at Gothenburg guarantee that the power connection and disconnection is an interaction that takes not exactly 10 min to finish. Nonetheless it should be noticed that this is at an ideal setting without any intricacies. As a general rule, the complete time for connection might be a lot higher because of the coordination that is needed among vessel and port teams, with times around 1 and 1.5 h being more realistic as recommended via CARB. Regardless of whether a vessel will really get shore power may likewise be influenced by availability of berth, failure of equipment, and other occasions, like force majeure, that may really reduce and put limits in the total time of utilizing the AMP facility. The port of Antwerp has provision for seven coastal onshore force association focuses at one terminal, for barges. In Hamburg, LNG barges are conveyed that provide power to ships at berth, effectively substituting MGO with LNG. Table 2 furnishes a rundown of known ports with shore power arrangement capacities. It is imperative that the force prerequisites length from generally little tugs, up to huge cruise ships and containerships across various ports. It tends to be seen that most installations are committed to either Ro-Ro, holder, or cruise ships, with exceptionally restricted establishments for bulkers or tankers. This might be credited to the way that the previous vessel types will in general visit similar port on different occasions, while the previous might be running on the spot market, and consequently show higher fluctuation in their port calls.



Existing and planned cold ironing facilities in ports..
Source: author's compilation and IAPH (2017)

Europe		North America		Asia		Oceania	
Antwerp (container, barges)	Belgium	Halifax (cruise)	Canada	Baku (container) *planned*	Azerbaijan	Auckland (cruise) *planned*	New Zealand
Zeebrugge (Ro-Ro)		Montreal (cruise)		Shangai (cruise)	China		
Helsinki (Ro-Ro)	Finland	Vancouver (container, cruise)					
Kemi (Ro-Ro)		Prince Rupert (container)		Qingdao (container)			
Kotka (Ro-Ro)		Los Angeles (Ocean Going Vessels/OGV)	U.S.A.	V.O.Chidambaranar (bulk)	India		
Oulu (Ro-Ro)		Long Beach (OGV)		Tokyo (cargo ships and ferries)	Japan		
		Oakland (container)					
Le Havre	France	San Francisco (OGV)		Busan	S. Korea		
Marseille (ferries)		San Diego (reefer ships)		Incheon			
Lübeck (Ro-Ro)	Germany	Seatlle (cruise)		Ulsan			
Hamburg (Cruise) *power by LNG barges*		Juneau (cruise)		Yeosu Gqangyang			
Amsterdam (river boats)	Netherlands	Pittsburg (bulk)		Taipei	Taiwan		
Rotterdam (barges)							
Oslo (Ro-Pax)	Norway						
Bergen (supply vessels)							
Goteborg (Ro-Ro)	Sweden						
Helsingborg (ferry)							
Piteå							
Stockholm (Ro-Pax)							
Milford Haven (tugs)	UK						

Table 2: Existing and planned cold ironing facilities in ports [131]

At the current electricity power price levels, onshore power is supposedly more affordable than the power generation on board. At last, a converse methodology where a vessel may give capacity to the grid can in principle happen should fuel costs permit it. Power ships (basically floating powerplants) are likewise ready to provide power to the grid, and a modest number has been worked to help nations confronting power deficiencies, with power outputs as much as 125MW per transport [20].

6.2 Provision of cold ironing as an emissions reduction option

The potential of emissions reduction activities that ports can use has been considered for VSRP and CI, accepting inclined toward full support [13]. Cold Ironing or Alternative Maritime Power (AMP) characterizes the methodology of giving electrical capacity to a vessel at port to satisfy the ship's energy needs while the vessel’s main and auxiliary engines are switched off. Military vessels depended on electrical force from the shore for a long time [14]. The utilization of electricity in transport has been predominantly related with the advantages through electric vehicles that outcome in outflows age at the wellspring of the energy creation offices and not at the area of vehicle action. Comparative advantages can be seen in the oceanic area at ports where the vessels are fueled by the grid.

6.3 Motivation for shore power

The utilization of AMP has been advanced in California with a regulation known as "At-Berth Regulation" that looks to decrease emissions from assistant motors during hoteling. The primary choice is using CI, or alternative technologies that bring about similar decrease of NOx and PM emissions (70% as of now, up to 80% by 2020). A similar system for CI had been in place in European ports, where since 2005 vessels remaining at EU ports for multiple hours (more than 2 hours), would be needed to utilize ultra-low sulfur fuel or then again use alternative technologies to achieve reduction of emissions including AMP as a choice. Beside these guidelines, the utilization of CI could likewise have monetary incentives when fuel prices are high, taking into consideration, that power from grid is sold at a lower cost than fuel.

While certain guidelines target explicitly the emissions during hoteling, it doesn't follow that AMP will be utilized all the more broadly. In Californian ports the local regulation specifies that terminal operators are needed to have the option to give shore power; in the EU this isn't the situation. The EU guideline on at-berth emissions is focusing on just SO_2 emissions, the decrease of which is likewise the objective of SECAs. Along these lines, a vessel can change over to MGO (at compartment or inside the SECA), or then again utilize scrubber frameworks to follow the guideline [6]. The latter, requires a critical venture that can surpass $6 million for each vessel, but offers compliance. The scrubber arrangement diminishes PM emissions too, however, limitedly affects NOx. In the range of 2005 and 2015 (the limit of Sulphur was 1% inside SECA, 0.1% at ports) a vessel calling at EU ports would have a higher incentive to invest into CI as it would replace the utilization of ultra-low sulfur fuel at the port. In different ports, the financial advantage of CI would be contrasted to the lower value of HFO. After 2015, because of the necessity to utilize MGO at the ocean too (inside SECA) the operator might be in an ideal situation investing into a general solution technique.

The emission savings from ships depending on AMP to control their hoteling activities at port, can be distinguished into local savings that the port gets and worldwide savings (or extra emissions) if the at-source emissions are represented. Overall, the most significant emissions are expected to decrease, for ports with moderately longer berth durations with late berthing prospects. Taking into consideration, specific pollutants, it can be expected that SO_2 emission reductions can be anticipated for non-EU and non-SECA ports where the pattern (depending on auxiliary engines) SO_2 emissions would be critical because of the greater sulfur content.

6.4 Challenges and opportunities regarding AMP

Contrasted with VSRP, slow steaming, or the utilization of low-sulfur fuel, the provision of CI for all vessels can be more challenging due to the hindrances in the

execution of AMP and the necessary investments for ship owners and ports. The main barrier to the more extensive utilization of AMP has been the absence of compatibility between the vessel and the grid as there is no uniform voltage and frequency around the world. The absence of standardization in primary distribution voltage prompted a variety from 440 V to 11 kV while a few vessels use 220 V at 50 or 60 Hz, and others depend on 110 V current [21]. The load prerequisites, also, fluctuate among various ship types and various sizes. Additionally, the critical retrofit costs on the vessel's side would make sense only for a vessel that has considerable long periods of services left, and this may thusly exclude older vessels. Khersonsky et al (2007) note two significant troubles in the further development of CI. The first is the extra expenses of retrofitting existing vessels to be AMP-ready [22]. The second thinks about the restricted space in ports to house the shore-side infrastructure. Another factor that needs to be addressed to current literature is the matter of berth accessibility. Berth accessibility is demonstrated to be a vital factor in the intensity of a port (Yeo et al., 2008) [23]. Taking into account that at start, only a couple of berths will actually want to give shore power, it is of outmost significance that when a retrofitted transport calls at the port, the respective CI-prepared compartment is free. Hence, the berth planning of the terminal operator should change to ensure that retrofitted ships are served by the CI-prepared compartments, without this affecting the total time spent at the port (waiting for berthing instructions from the terminal that can result in a delayed departure of the vessel). A final challenge is introduced by Innes and Monios (2018) who investigated and noted that in case of smaller ports, various little compartments might require CI establishments and installations that will increase the expenses because of extra units and longer cables and wires required [18]. Nonetheless, there are opportunities that might help with promoting extension of the utilization of CI in the near future. Legislation and newly established guidelines as well as regulations, may create an impact to the extended utilization of AMP across ports. CI could be an ideal option for ship owners due to the
greater expense of the ultra-low sulfur fuel, if at-berth emissions are the only ones regulated. Given the overall pattern to expand RES, CI can, also, lessen the ecological effect of ports on a worldwide scale as well. The EU has set targets through its mandates so that by 2020, 20% of energy production in a part state is given by RES, and it is expected that the rate will be radically increased in the future.

The appropriation of CI from ports all throughout the planet can prompt a cascading type of influence where more port administrators are influenced and follow the examples of effective executions. Tseng and Pilcher (2015) focused on Taiwan for instance and as indicated by the aftereffects of their meetings, some port operators consider CI as the future and that this is an international trend they ought to follow. Another disadvantages and limitations of CI are that electricity powered by AEs is by and large less expensive than land-based power supply and electricity fueled by AEs is exempt [25] from national energy and power taxes inside the EU. Nonetheless, in 2011 the EU conceded special exemptions to Germany [26] and Sweden [27] to permit these nations to supply shore power at a reduced rate (i.e., without paying local environmental energy taxes) as a motivating force for shipping companies to utilize shore power. Considerable capital venture should be made in land-based power supply utilities, and this is a negative aspect of CI, on the grounds that huge investments should be made. Last but not least, shore power must be provided while vessels are at berth and not while maneuvering or during navigation or transshipment. Port environments would, in this manner, actually be dependent upon a specific level of emissions.

6.5 Safety

Safety issues can occur while ships are being connected and disconnected from shore power. There are safety and operational concerns about the ship-to-shore cable connections. Cable reel system should be appropriate for handling because it can cause damages and safety issues to both vessel and crew onboard vessel.

7. Ammonia

7.1 Properties of Ammonia as marine fuel and its financial perspective

Ammonia has drawn a wide interest as a source of zero emission fuel for shipping. Practically all ammonia being used today is produced using hydrocarbons, and as such presents almost no carbon minimization advantage, while simply adding costs. Conversely, green ammonia – produced by electrolysis controlled by renewables or nuclear – is an incredible source of zero-emission fuel, given that related NO_X emissions are managed appropriately. Nonetheless, green ammonia is at present only produced in small amounts, and a gigantic speculation program would be required not only to produce a significant stock of green ammonia, but also to drive down the expenses for the fuel to become monetarily practical for the shipping industry.

The expense of ammonia production will vary depending upon the production course. The natural gas cost is a central point in the expense of producing ammonia from natural gas while the electricity cost is a main factor in the expense of producing ammonia which is renewable dependent on electricity, where the last is the main production way of ammonia as marine fuel. Bicer et al., (2016) shows that around 70-90% of the current production cost of ammonia, in general, originates from the expense for natural gas [28]. In another study, it is demonstrated that ammonia costs can be 100-200 USD per ton higher than cost of production, because of transportation and storage cost [38].

The ammonia production cost for renewable ammonia (the ammonia to be utilized as marine fuel) was assessed to range from $130 to 440 for each ton of ammonia for the different cases studied by Tuna et al., (2014) [39]. In another study, the expense of ammonia creation in 2040 for five courses is compared: regular course through steam reforming of natural gas, with and without carbon capture and storage, followed by the Haber-Bosch synthesis [40]; electrolysis of water followed by the Haber-Bosch blend; electrochemical ammonia production (direct electrochemical nitrogen decrease). These expenses are per energy unit based on lower heating value and does not consider that various fuels and vessel propulsion systems have various efficiencies.

Lloyd's Register (2017) have assessed the extra drive framework cost for an ammonia fueled vessel to be around 2-60% when utilizing internal combustion engine and 8-300% when utilizing fuel cells, comparative with a customary HFO-fueled vessel [41]. De Vries (2019) have assessed the capital and functional costs for the different vessel propulsion systems utilizing ammonia as fuel, however, the figures are so far exceptionally uncertain as these innovations are under development [30]. There are, also, expenses for circulating ammonia. DNV GL (2019) propose that these expenses could be like transporting LNG measured on a volume bases and assumes that expenses would be between 20-70 $ per MWh [42].

7.2 Environmental aspects of ammonia as shipping fuel

The available tests on combustion engines show issues with ammonia slip, NO_X emissions and possibly outflows of CO and hydrocarbons (contingent upon pilot fuel) and N_2O. These emissions can probably be handled with after treatment, either TWC (three-way catalyst) if the combustion is stoichiometric or SCR/EGR (Selective Catalytic Reduction/Exhaust Gas Recirculation) for lean combustion. Notwithstanding, the ammonia slip and low effectiveness in combustion with a high fraction of the pilot fuel are factors that would need to be reviewed before tests on vessels.

Ammonia released into the atmosphere can have wellbeing hazards if at high concentrations. Moreover, it will contribute to creation of secondary particles and to eutrophication.

An LCA, considering specific ecological effects, of ammonia production pathways utilizing the Haber Bosch measure and non-fossil fuel energy sources for the hydrogen creation report the lowest GHG emissions from the utilization of hydropower when contrasted with nuclear, biomass and civil waste [28]. Furthermore, Bicer and Dincer (2018) evaluate the GHG emission reduction potential from marine transportation by replacing traditional heavy fuel oil with renewable hydrogen and ammonia and find that ammonia and hydrogen used as double fuel with heavy fuel oils (50%) can diminish the GHG emissions per ton-kilometer by around 30% and 40%, respectively [29].

While producing renewable ammonia (from electricity) an electricity contribution of 3-4 times the actual work propelling the vessel is required.

7.3 Safety perspective of ammonia

As far as wellbeing issues connected to ammonia, spillages, leakages and the potential exposure to people and the natural environment appear to be key concerns.

Ammonia is a poisonous and destructive substance and possible leakage, and spills will be hazardous to the human and the environment including aquatic life (the last mentioned if spillage in water). Ammonia is for instance hazardous to breathe in throughout specific levels and time periods and is harmful for creatures living in water with potential long-term impacts [30]. The limit points for ammonia exposure at working environments in Sweden are 20 ppm for 8 hours and 50 ppm for 5 minutes. As indicated by de Vries ammonia can be lethal to people at 2700 ppm when exposed for a length of 10 minutes [30]. Moreover, Valera-Medina et al. (2018) [31] report that less than thirty minutes of exposure at 2000-3000 ppm might cause death, while Klüssmann et al. (2009) report that the quickly dangerous to life or health limit is assessed to 300 ppm [32]. Safety issues around ammonia have, for instance, been analyzed connected to the utilization of anhydrous ammonia as a refrigerant in mechanical compression systems at industrial facilities, where it has been replaced generally [33].

Ammonia is biodegradable and when existent in water will changed over into ammonium particles (NH4+) which are innocuous for humans and plants [30]. Notwithstanding, as indicated above ammonia released in water might harm creatures in the water whenever exposed directly and potential long-term impacts should be explained. Ammonia released in the dry air will due its lower density dilutes and vanish upwards; however, several components impact how quick and how much ammonia diffuses in the air [31].

Despite the fact that there are handling experience and guidelines connected to the transport and utilization of ammonia (bulk ammonia transport vessels follow the prerequisites of the 2014 International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk - IGC Code, Ash and Scarbrough, 2019), specific safety regulations connected to the utilization of ammonia as marine fuel will be required in the event of implementation [34]. These regulations should be viewed as when planning the fuel handling system for bunkering as well as during operation. This may add some expenses for the ammonia pathways. For instance, as per De Vries (2019) separate spaces for fuel storage and fuel treatment rooms seem to be required and the fuel lines must be situated with a distance to the shell or considered in alternate ways which impact the utilization of the space ready [30].

Connected to ammonia fuel system on ships gas detention systems, ventilation and suitable chemically resistant protective clothing and other safety measures for those taking care of the fuel will be required [34], [30]. Ammonia can likewise be distinguished by its odor.

Minor ammonia slip can, as per studies alluded to by Klüssmann et al., (2019), be eliminated along with NO_X with altered SCR catalyst after treatment while bigger slips may require the execution of a devoted ammonia trap or oxidation catalyst [32]. Klüssmann et al., (2019) propose that storing of ammonia in mineral salts or metal ammine edifices can lessen safety issues related to on board storage of fluid ammonia. Nonetheless, this innovation is under development [32].

Additionally, Ash and Scarbrough (2019) specifies the danger of arrangement of hydrogen cyanide (HCN, which is exceptionally harmful) in combustion of a hydrocarbon fuel and ammonia (Gail et al., 2012) [34], [35]. However, they guarantee that reviews demonstrate adequate levels in SI and CI-engines (Moussa et al., 2016; Baum et al., 2007) and that there have been no reports in regard to emission of hydrogen cyanic when ammonia and hydrocarbon fuels are utilized in ICE however that there is as yet a danger (Ash and Scarbrough, 2019) [34], [36], [44].

Ammonia has a generally low combustibility compared to different fuels which imply a relatively low risk of fire; however, it can frame explosive mixtures with air (though, larger amounts are required contrasted with numerous different fuels as indicated by Klüssmann et al. (2019)) [32]. In any case, as featured by de Vries (2019), since hydrogen, which can be acquired from cracked ammonia, represents a very combustible gas, this danger should be thought of [30].

As far as rules and guidelines for ammonia as a fuel, it is shown that "MAN Energy Solutions is as of now working with DNV-GL and Navigator Gas on a beginning phase hazard evaluation to utilize ammonia as a shipping fuel [34] and that ABS connected to the joint development project for an ammonia-powered feeder container vessel (between MAN, SDARI and ABS) will "assess safety related issues and contribute to the improvement of rules and principles according to ammonia as a fuel" [37]. The IGF Code (International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels) would probably be additionally evolved in the event of utilization of ammonia as marine fuel [30].

Public acknowledgment for the use of ammonia as fuel is significant as this will impact all stakeholders (producers, users, policy makers). This will be influenced by public preparation and the development of events and observants of safety guidelines as well as media.

8. Methanol

8.1 Combustion of methanol on board ships

The actual CO_2 emissions from combustion of methanol depend on the carbon content per MJ fuel. The carbon content can change marginally as indicated by the purity of the fuel; in this way, purity of the fuel is well-controlled in the production level. This study uses as a premise that methanol combustion emits 69 g CO_2 for each MJ methanol combusted [101].

CO_2 from combusted bio-methanol is viewed as environment neutral and is therefore not considered a GHG gas [102]. This happens because it is accepted that CO_2 emitted from biomass-based fuel is removed from the atmosphere once new biomass is grown to replace the biomass used to produce the fuel [45]. CH_4 and N_2O emissions from methanol are thought to be negligible [103]. Moreover, SOx emissions depend on sulfur content of methanol, which is negligible too [103].

There have been not many tests estimating the NOx emissions from methanol combusted in marine engines. Wärtsilä has been doing tests on NOx emissions from methanol against those from HFO in two engine models: pre-tests on the Wärtsilä Vasa 32, and full tests on the Sulzer Z40S-MD [104]. Their outcomes show that NOx emissions were roughly 40% of emissions from HFO from similar engines at a similar load. Nonetheless, the NOx emissions were not as low as Tier III levels. It is therefore expected that NOx emissions during combustion are diminished by around 60% when running on methanol contrasted with HFO. MAN Diesel has performed tests with a methanol in marine diesels bringing about a 30% decrease in NOx emissions compared to diesel [105].

(Albeit the results of tests from Wärtsilä [104] and MAN [105] may vary, both show a huge decrease of NOx reduction when utilizing methanol. Also, NOx emissions are subject to combustion condition, implying that any parameter showing NOx emissions per MJ fuel will contain some uncertainty).

Additionally, the Wärtsilä tests showed that the fuel efficiency is something similar or better when running on methanol. Stena's experience indicates that they have better fuel-efficiency in the order of 1-2% when running on methanol, in spite of the fact that they have not performed tests to report the adjustment in efficiency. It is subsequently expected that the energy effectiveness in marine engines remains the same and does not alter when running on methanol. There is increased lubrication oil utilization when running on methanol, however this was considered unimportant.

The below combustion factors for methanol are utilized. All variables rely upon motor sort to a specific degree.

The expenses of methanol as fuel are assessed according to one point of view: that of the shipowner. The fundamental cost of methanol from the shipowner's point of view is compared to estimations of the expense of methanol production.

The payback time for running a vessel on methanol in ECAs will be reliant upon the extra capital expenses of methanol propulsion and the potential extra savings/additional expenses in case that methanol is less expensive or more costly than the other fuel options. In an ECA, the ordinary fuel for examination will be MGO; in any case, the shipowner can also consider utilizing HFO with an exhaust gas cleaning system (scrubber). Scrubbers have a certain capital and operational cost; however, it permits the shipowner to run on generally modest HFO in ECAs. An estimate of the payback time for a ship using a scrubber is hence likewise determined for point of view.

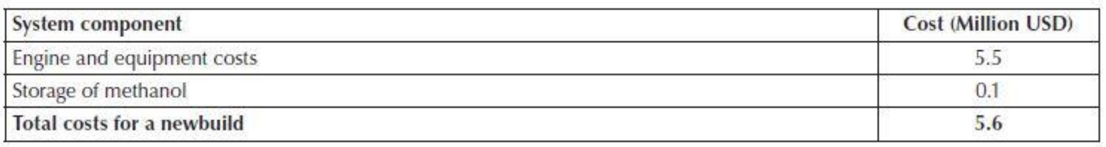
LNG can likewise be another option. LNG has high capital expenses yet might be a less expensive fuel than MGO and to some degree less expensive than HFO [119].

Safety systems which constitute the methanol fuel system have some extra capital expenses, fundamental for methanol propulsion. These extra expenses depend on the cost of the items introduced in Table 2 and Table 3 and determined for two cases:

- Newbuild vessel

- Retrofit of existing vessel

The capital expenses determined are relevant for a ro-ro vessel with 24000 kW installed main engine power and tank capacity with regards to 3 days of sailing. There are, as previously discussed, a few differences among the different types of vessels, yet this assessment is a coarse estimate used to show how the extra capital expenses interact with the price of fuel to decide the payback for a vessel running on methanol. The expenses for the important extra components introduced in this section depend on discussion with the industry and address current systems. The extra capital expenses for a newbuild with a methanol fuel system are introduced in Table 3, while the retrofit case is introduced in Table 4.



System component	**Cost (Million USD)**
Engine and equipment costs	5.5
Storage of methanol	0.1
Total costs for a newbuild	**5.6**

Table 3: Approximate additional costs for a newbuild with the total methanol fuel system [130]

System component	**Cost (Million USD)**
Engine costs	3.5
Other equipment	3.5
Additional shipyard costs	3.5
Total costs for retrofit	**10.5**

Table 4: Approximate additional costs for retrofit with the methanol fuel system [130]

In the following the expenses in Tables 3 and 4 are utilized as input to the computation of payback time of a methanol fuel. For examination, a SOx scrubber for a similar total introduced power is expected to cost 6 MUSD for a retrofit, with this expense being decreased by 50% for a newbuild. These evaluations depend on DNV GL experience and statements from scrubber manufacturers.

The extra expenses of methanol propulsion for a newbuild are around half the size of those for a retrofit case, basically because of the way that the tank of a newbuild is consolidated into the plan of the vessel from the beginning, and its placement in the vessel will not comprise an extra expense for the shipowner. For a retrofit, we have assumed a different tank not integrated into the existing vessel and this will constitute an extra expense. Other than the tank cost, a newbuild is less expensive to run on methanol since it is simpler to use a double fuel engine than to custom retrofit an engine.

These extra capital expenses were used as input to calculate the payback time of a methanol fuel system compared with fuel switch (use of MGO) or installing a scrubber (use of HFO) to adapt to the newly established regulations and environmental prerequisites in ECAs [120].

The calculation for payback time depends on a suspicion of the time spent in ECA as a proportion of the entire sailing time and the corresponding fuel consumption. The more fuel the vessel consumes in ECA the greater the chance to save cash by purchasing cheaper fuel. The payback time is determined as the time it takes for the potential fuel cost savings to recover the initial capital expenses for funding this investment, based on changing rates of ECA exposure and different price differences of methanol contrasted with MGO. Fuel costs are determined for 15 years after the initial capital investment and a rebate rate of 8% is utilized.

Two MGO price scenarios are used to estimate the payback time for a methanol fuel system contrasted with fuel change to MGO. The high price scenario assumes a price near those of mid-2014 Rotterdam MGO costs (865 USD/ton). The low piece scenario assumes a MGO price near those of mid-2015 Rotterdam MGO costs (450 USD/ton). A computation of the payback time of picking HFO with a scrubber versus fuel switch to MGO is also performed as a comparison [121].

To decide whether the methanol prices important to accomplish a specific payback period are sensible, we should compare the necessary methanol process with historic methanol prices. Recorded costs are displayed in Figure 3.

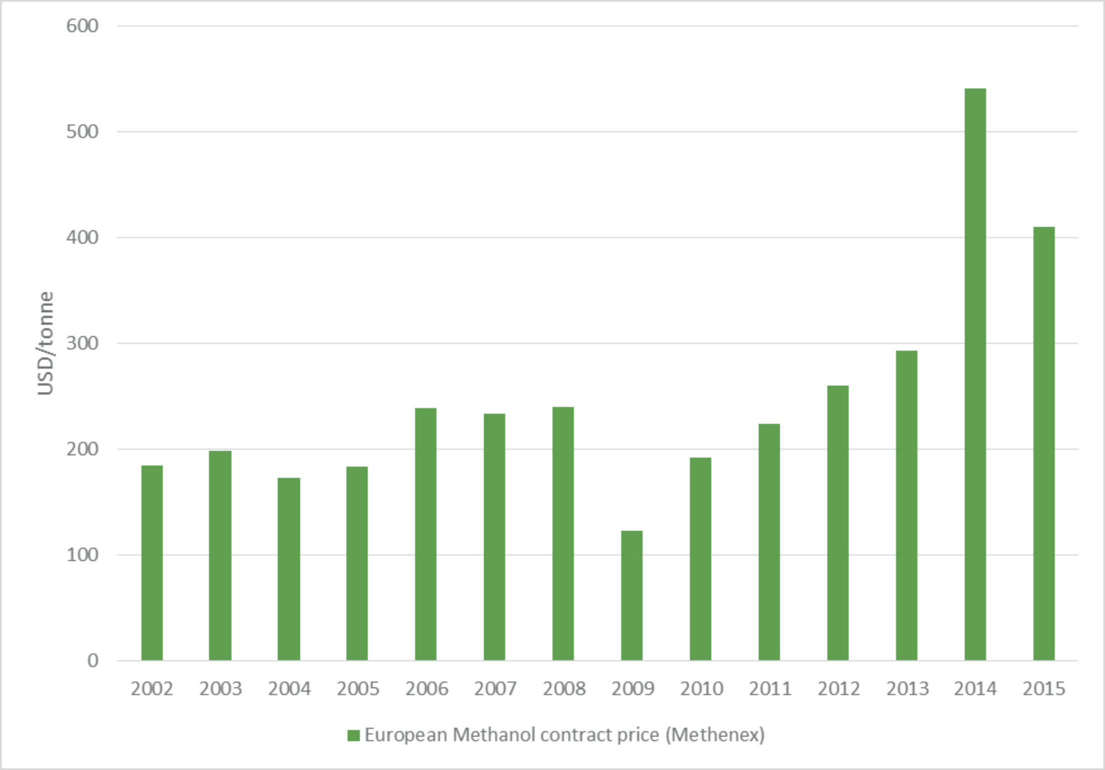
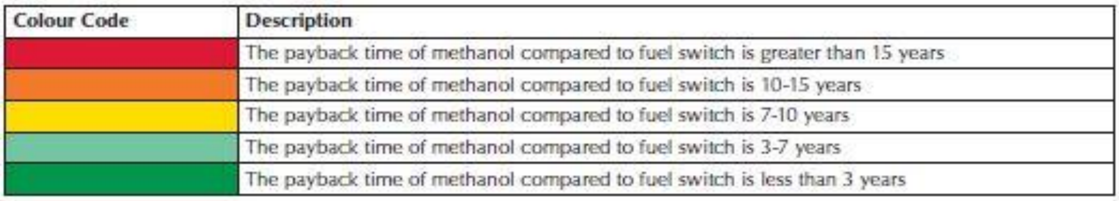


Figure 3: Historical Methanol Prices [130]

The payback time is given a shading coding to reflect how alluring the payback period is for a shipowner, displayed in Table 5.



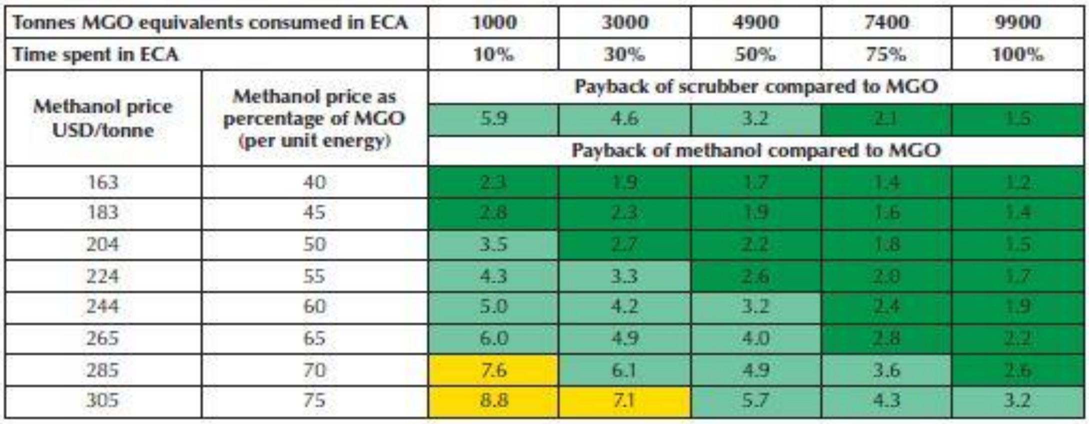
Colour Code	Description
🟥	The payback time of methanol compared to fuel switch is greater than 15 years
🟧	The payback time of methanol compared to fuel switch is 10-15 years
🟨	The payback time of methanol compared to fuel switch is 7-10 years
🟩	The payback time of methanol compared to fuel switch is 3-7 years
🟩	The payback time of methanol compared to fuel switch is less than 3 years

Table 5: Color coding describing payback time intervals [130]

The case analyzed in Table 5 shows the payback time of a newbuild vessel running on methanol with the low MGO price scenario. This MGO price addresses the current MGO market price. The outcomes show that with a low MGO price scenario, the payback time of methanol is somewhat high. For instance, if the vessel invests 100% of its time inside the ECA zone, and the cost of methanol is 75% of MGO (on energy basis), the payback time is 6.8 years. For most shipowners, this is a generally long payback time thinking about that the cost of fuel, and in this way the payback period, is very unpredictable.

Taking a gander at Table 5, the competitive methanol price expected to accomplish a payback time lower than that of a scrubber is, in that situation, unrealistically low at 85 USD per ton. Figure 3 shows that a low price for methanol has not been seen historically. This shows that methanol is certainly not an alluring choice from a price point of view for a newbuild vessel and the present MGO costs (for example the low-price situation).

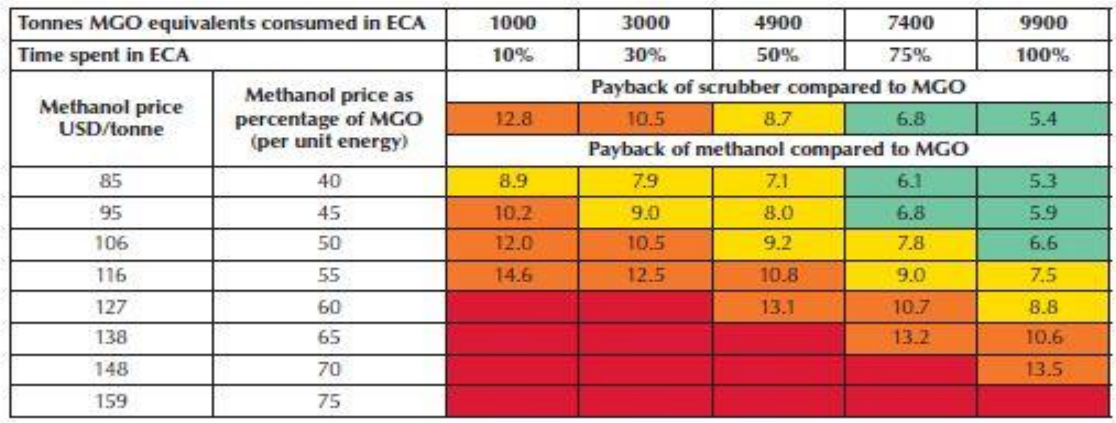
The case introduced in Table 6 addresses the payback time of a newbuild running on methanol with the high MGO price scenario. This MGO price addresses the MGO market cost from mid-2014, preceding the drop in oil price. The results show that with a high MGO price scenario, the payback time of methanol is relatively low. The serious methanol price expected to accomplish payback time lower than that of installing a scrubber is realistic for this situation, at 204 USD per ton. This shows that methanol is an alluring alternative from a price viewpoint.



Tonnes MGO equivalents consumed in ECA		1000	3000	4900	7400	9900
Time spent in ECA		10%	30%	50%	75%	100%
Methanol price USD/tonne	Methanol price as percentage of MGO (per unit energy)	Payback of scrubber compared to MGO				
		5.9	4.6	3.2	2.1	1.5
		Payback of methanol compared to MGO				
163	40	2.3	1.9	1.7	1.4	1.2
183	45	2.8	2.3	1.9	1.6	1.4
204	50	3.5	2.7	2.2	1.8	1.5
224	55	4.3	3.3	2.6	2.0	1.7
244	60	5.0	4.2	3.2	2.4	1.9
265	65	6.0	4.9	4.0	2.8	2.2
285	70	7.6	6.1	4.9	3.6	2.6
305	75	8.8	7.1	5.7	4.3	3.2

Table 6: Sensitivity price newbuild with a high MGO price scenario [130]

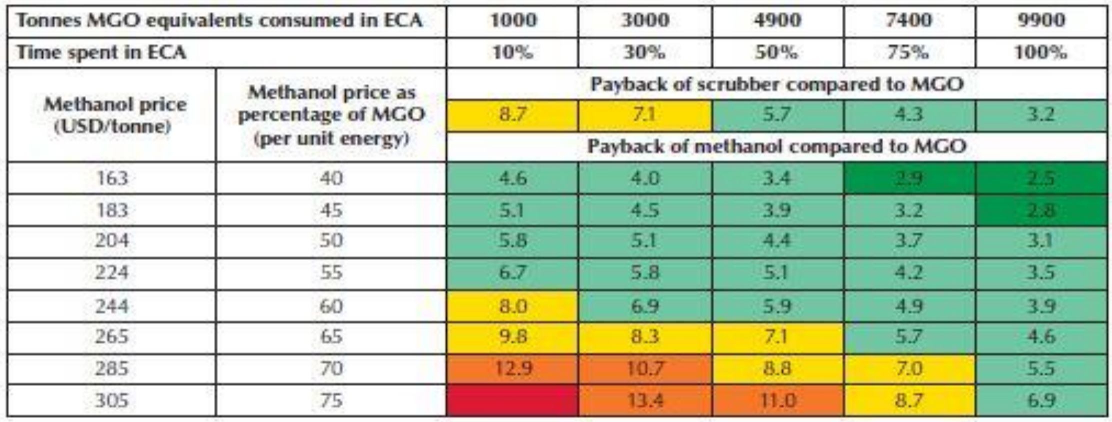
The case introduced in Table 7 addresses the payback time of a vessel retrofitted to run on methanol with a low MGO price scenario. The outcomes show that with a low MGO price scenario the payback time of methanol is high. The competitive methanol price expected to accomplish a payback time lower than that of installing scrubber is for this situation unrealistically low at 85 USD per ton. Therefore, these lines show that methanol will never again be an appealing alternative according to a price point of view.



Tonnes MGO equivalents consumed in ECA		1000	3000	4900	7400	9900
Time spent in ECA		10%	30%	50%	75%	100%
Methanol price USD/tonne	Methanol price as percentage of MGO (per unit energy)	Payback of scrubber compared to MGO				
		12.8	10.5	8.7	6.8	5.4
		Payback of methanol compared to MGO				
85	40	8.9	7.9	7.1	6.1	5.3
95	45	10.2	9.0	8.0	6.8	5.9
106	50	12.0	10.5	9.2	7.8	6.6
116	55	14.6	12.5	10.8	9.0	7.5
127	60	🟥	🟥	13.1	10.7	8.8
138	65	🟥	🟥	🟥	13.2	10.6
148	70	🟥	🟥	🟥	🟥	13.5
159	75	🟥	🟥	🟥	🟥	🟥

Table 7: Sensitivity price newbuild with a low MGO price scenario [130]

The case introduced in Table 8 addresses the payback time of a vessel retrofitted to run on methanol with a high MGO price scenario. The results show that with a high MGO price scenario, the payback time of methanol is moderately low. The competitive methanol price expected to accomplish a payback time lower than installing a scrubber for this situation is realistic at 204 USD per ton. This shows that methanol is an attractive choice according to an economic point of view.



Tonnes MGO equivalents consumed in ECA		1000	3000	4900	7400	9900
Time spent in ECA		10%	30%	50%	75%	100%
Methanol price (USD/tonne)	Methanol price as percentage of MGO (per unit energy)	Payback of scrubber compared to MGO				
		8.7	7.1	5.7	4.3	3.2
		Payback of methanol compared to MGO				
163	40	4.6	4.0	3.4	2.9	2.5
183	45	5.1	4.5	3.9	3.2	2.8
204	50	5.8	5.1	4.4	3.7	3.1
224	55	6.7	5.8	5.1	4.2	3.5
244	60	8.0	6.9	5.9	4.9	3.9
265	65	9.8	8.3	7.1	5.7	4.6
285	70	12.9	10.7	8.8	7.0	5.5
305	75	🟥	13.4	11.0	8.7	6.9

Table 8: Sensitivity price retrofit with a high MGO price scenario [130]

In the cases with a low MGO value as indicated by the current market, the methanol prices are important to accomplish a payback time lower than that of introducing a scrubber is 85 USD per ton on account of both a newbuild and a retrofit. This cost is excessively low contrasted with the recorded costs of methanol to be considered reasonable. Methanol as fuel is consequently not a financially attractive choice in given low MGO costs. Given the high MGO price scenario, the methanol prices can accomplish an important payback time lower than that of installing a scrubber which is

204 USD per ton for a newbuild or retrofit. This methanol cost has happened in the past and can be reasonably expected, making methanol a more financially appealing alternative. The outcome is additionally reliant on the time spent in ECA, and if this time is approaching nearer to 100%, methanol as fuel shows extraordinary potential in all cases, with the exception of a retrofit in combination with a low MGO price.

8.2 Identifying the environmental benefits of methanol [122]

To distinguish the ecological advantages of utilizing methanol as marine fuel, the total lifecycle emissions of methanol propulsion on ships are contrasted with ordinary fuels – MGO and HFO. The lifecycle emissions of SOx, NOx and greenhouse gases (GHGs: CO_2, CH_4 and N_2O) are identified for the production and emission phases of methanol production.

The system boundaries for the lifecycle emissions are well-to-propeller, implying that the emissions of extracting and refining crude oil energy sources are seriously considered. The whole lifecycle can be divided into two fundamental stages: well-to-tank (the total emissions of extracting crude materials, creating and transporting the fuel) and furthermore, tank-to-propeller (the emissions from combustion and possible leakages).

The emissions of CO_2 and SOx from the combustion stage are subject to the carbon and sulfur content of the fuel being referred to. The emissions of CH_4, N_2O and NOx depend on temperature and combustion conditions. These values are likely to change with engine load and rpm, however average emission factors in g/MJ fuel are used in this study. All lifecycle emissions are standardized per MJ content of fuel.

Emissions of CH_4 and N_2O have various contributions to global warming. These emissions are subsequently standardized to g CO_2 equivalents, with the total GHG emissions can be summed and the lifecycle GHG emissions from each fuel type can be compared. The CH_4 and N_2O emissions are converted to CO_2 equivalents utilizing a 100-year time horizon. This implies that the CH_4 and N_2O emissions are standardized by their impact on a global warming of a 100-year time scale. Standardization factors are given in Table 9.

Emissions	Global warming potential for 100-year time horizon (g CO_2 equivalents/g emissions)108
CO_2	1
CH_4	25
N_2O	298

Table 9: Global warming potential of CH_4 and N_2O [129]

CH_4 and N_2O are not produced in large quantities from combustion of methanol or other conventional marine fuels, but yet, they are taken into consideration on the grounds that they are emitted in the production process and their inclusion is significant for the completeness of any lifecycle GHG inventory.

SOx and NOx emissions are significant in a maritime context essentially in view of their harmful impacts on human health, land-based infrastructure, and natural habitats. Their emissions nearby ports or in places where people are present where they do most harm and damage, however, on a local level they additionally contribute acid rain creation which has corrosive effects on infrastructure and potentially local acidification of the marine environment. Their lifecycle emissions are evaluated here.

Particulate emissions are significant from a human health point of view, with black-carbon also needing attention as a short-lived environmental change forcer and a potential ice-dissolve accelerant. Notwithstanding, such emissions are outside the extent of this study.

Furthermore, methanol combustion emit formaldehyde, which has serious impacts on human health, but yet this is outside the extent of this study. Different issues outside the scope incorporate the conceivable cooling impacts of SOx and aerosols in the air, the formaldehyde emissions from methanol and the uncertainty of NOx's effects on climate.

8.3 Comparing lifecycle emissions of methanol to conventional fuels

8.3.1 Greenhouse gas emissions

The lifecycle emissions from methanol production with natural gas are overwhelmed by emissions from methanol production and combustion in marine engines.

Since emissions from methanol combustion and methanol production at the plant depend on the chemical synthesis of natural gas and methanol respectively, there is little variation in regard to these emissions. The emissions from extraction and transport of natural gas can be fundamentally different as per where the natural gas is produced. Be that as it may, these emissions are small contrasted with those from combustion and production.

Emissions from the well-to-tank period of methanol produced with natural gas are somewhat higher than relating emissions from MGO and HFO. For comparison, the lifecycle emissions of LNG from well-to-propeller are found to be from 72-90 g CO2 eq/MJ, implying that the lifecycle GHG emissions of LNG are in the order of magnitude of conventional fuels.

Given that biomass is produced utilizing a moderately clean electricity mix, the lifecycle GHG emissions of methanol production is less than 50% of traditional fuels. The environmental and ecological advantages of methanol are highly reliant upon the raw materials used to make it. Indeed, bio-methanol isn't really much improved over MGO in case it is made with an electricity mix that does not have a high share of renewables.

8.3.2 Lifecycle NOx and SOx emissions

The lifecycle emissions of SOx and NOx have likewise been determined based on the ELCD data base [101], and data in Figure 4 and 5. The emissions of SOx and NOx from the well-to-tank production of bio-methanol depend on values for methanol produced from biomass by means of black liquor [101].

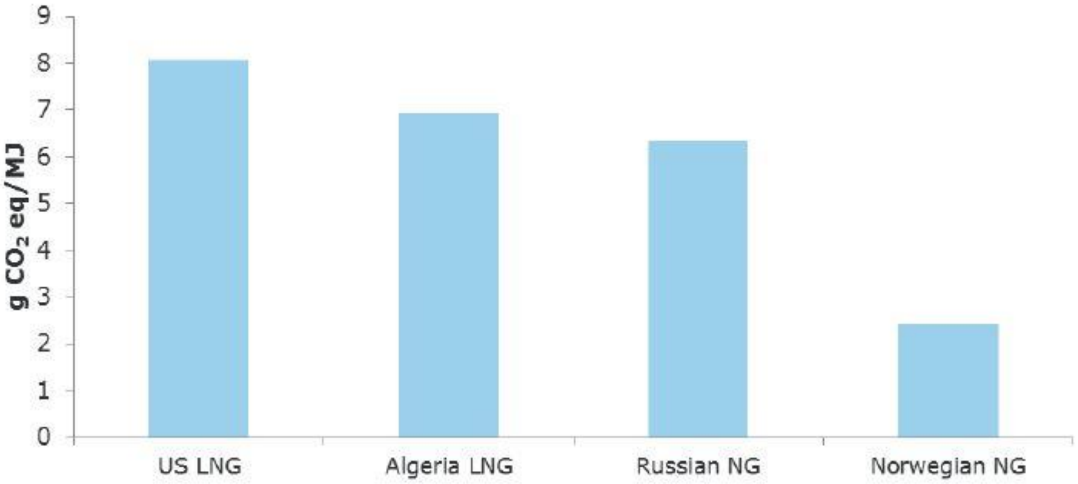


Figure 4: GHG emissions of natural gas extraction [129]

The lifecycle emissions of NOx are diminished by around 55% when utilizing methanol contrasted with conventional fuels. The lifecycle emissions of SOx are diminished by around 92% when utilizing methanol, contrasted with traditional fuels.

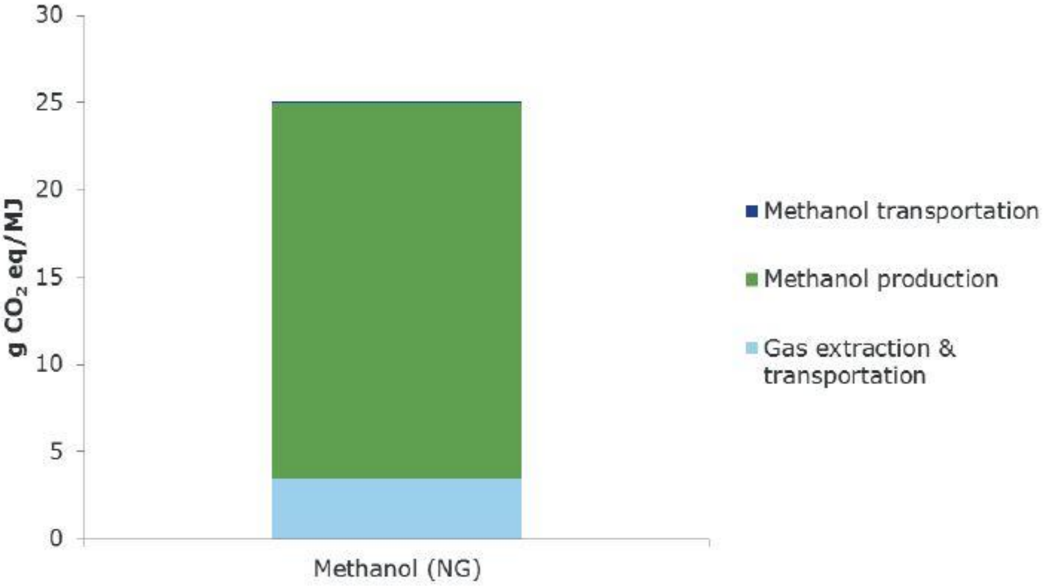


Figure 5: Well-to-tank GHG emissions from methanol produced with natural gas [129]

Figure 6 and Figure 7 represent that the NOx and SOx emissions are dominated by the combustion in marine engines, and that implementing measures which lessen NOx and SOx from ships is a powerful way to minimize these sorts of emissions on a worldwide level.

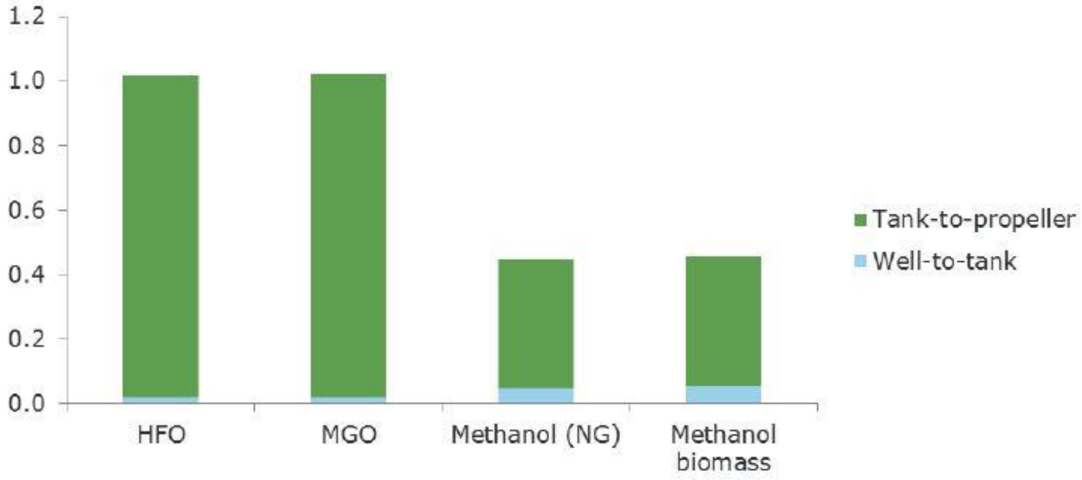


Figure 6: Lifecycle emissions of NOx from methanol compared to conventional fuels [129]

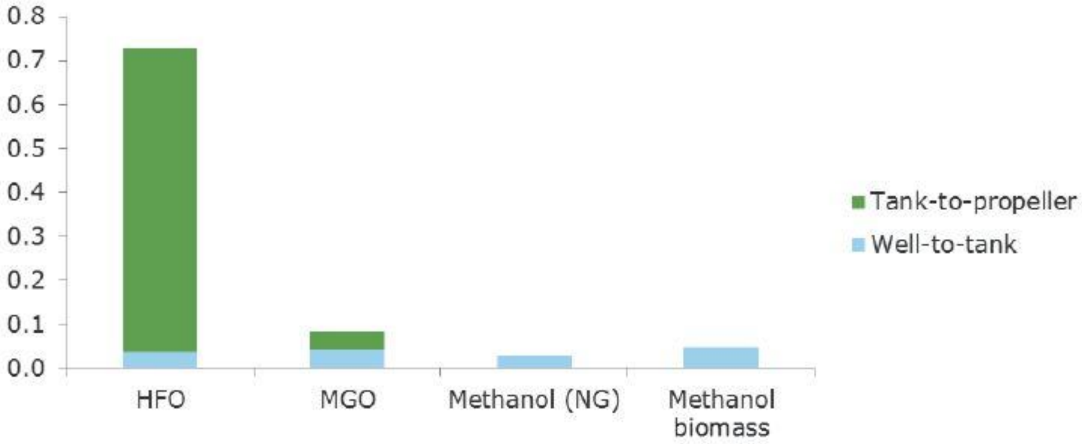


Figure 7: Lifecycle emissions of SOx from methanol compared to marine conventional fuels [129]

8.4 Encouraging the use of methanol [123]

Based on the above, sulfur is the only emissions type for which methanol is a clear option to fulfill guidelines and regulations of IMO.

The current incentives for shipowners to pick methanol over the other fuels are the SECA requirements which suggest the utilization of low sulfur fuels or scrubbers. The CAPEX and the vulnerability of fuel savings are the current most significant barriers for a shipowner for choosing methanol over another low-sulfur fuel. The assessment of monetary possibility shows that a scrubber has a comparative payback time, however, less uncertainty. This happens because it provides more certainty to a shipowner of saving money running on HFO than running on methanol, given the fluctuations of MGO and methanol price.

The SECAs give motivation to a shipowner to choose a low-sulfur fuel, of which methanol is only one possibility, and not really the most financially reasonable. To empower the use and choose of methanol, rebates could be granted which would minimize the burden of the capital expenses and put forth the business case for methanol less certain.

In Norway, the NOx fund gives an illustration of one plan which has been used to encourage the utilization of low NOx innovations like specific catalytic reduction (SCR) and LNG. The Business Sector's NOx Fund was initiated after the presentation of the Norwegian assessment on NOx emissions in 2007. The fund depends on an industry/authority agreement for a period of ten years, including tax relief and quantitative NOx reduction responsibilities. Rather than paying a tax on a state (of critical size), enterprises who are part of the NOx fund pay a much lower (around 1/5 of the state tax) into the Fund. The enterprises should carry out NOx decreasing measures to a degree that the reduction responsibilities are met. For this, they would then be able to apply for monetary support for the installation of NOx decreasing technological innovations (going beyond existing guidelines), receiving up to 80% coverage of their investment. Shipowners should report that the technology in question, potentially methanol, has a recorded NOx decreasing effects, and the help is dimensioned by real accomplished and recorded emission reduction during operations. The Norwegian NOx asset has provided such appropriations for LNG, SCR, low-NOx engine replacements, engine solutions, battery/hybrid vessels, EGR and different fuel-saving technologies with success. This has catalyzed the market for example for LNG propulsion in Norway.

Albeit the Norwegian NOx fund isn't really a very applicable model in many places around the world, there are a few conclusions which can be derived from its effectiveness. The success of the NOx fund is reliant upon the NOx tax. Cash gathered by the NOx fund as the reduced NOx tax that its individuals pay to the fund goes altogether and straightforwardly to reduce NOx. The fund is believed to be more effective than a "passive" NOx tax, which is a burden on industry, however, does not really provide the industry with a method for diminishing their emissions.

Data and experience from the NOx fund shows that shipowners need both the carrot and the stick as to stimulate alternative fuels. A mechanism which permits the financial burden (taxes) of emissions to commit straightforwardly to industry's ability to minimize the emissions takes into account the take-up of new technological investments.

Methanol could be urged through a plan to minimize carbon emissions. The advantage of encouraging methanol through a carbon tax, or a plan to reduce carbon footprint, is that bio-methanol is a measure, which reduces CO_2 emissions altogether, whereas LNG can reduce CO_2 emissions just partially, and scrubbers do not have a CO_2 reduction impact by any means. Furthermore, methanol lessens SOx and particles like LNG or NOx (albeit not as efficient as a significant number of the LNG solutions).

Methanol created with natural gas does not decrease CO_2 emissions according to a lifecycle viewpoint, however, could be considered as a CO_2 measure in that methanol as fuel can possibly be made from biomass, as opposed to conventional fuels and LNG, which are fossil-based by definition.

9. LPG

9.1 Outline of LPG, its production, quality, transportation, and pricing [124]

The expression "LPG", Liquefied Petroleum Gas, is applied to combinations of light hydrocarbons which can be liquefied under moderate pressure at a normal temperature yet are vaporous under normal environmental conditions.

It consists prevalently of propane and butane (especially butane and iso-butane), propylene and other light hydrocarbons and its chemical composition can differ. In certain nations, the mix varies according to the season. Since LPG can be liquefied at low pressure at barometrical temperature, its storage and transportation are simpler than of other gaseous fuels. It is stored under pressure in cylinders or tanks.

LPG is produced either from natural gas handling and processing – fundamentally – or from oil refining. LPG is a result of both these processes. As of now, over 60% of worldwide LPG supply comes from natural gas processing plants, yet the share varies especially among districts and nations. It isn't just accessible and abundant in supply; however, it is economical and naturally solid.
The makers of a wide range of engines for marine and particularly for outboard uses have explicit requirements for the quality of the fuel utilized in their engines.

Modern equipment and advanced technological innovations come regularly with expanded prerequisites as far as the quality of fuel is concerned. Similar holds for LPG and specifically considerably more so when this is utilized in marine engines that need to offer consistent and reliable service.

Fuel quality prerequisites accordingly differ. Otto or spark ignition fuels should be resistant to detonation when compressed in a flammable mixture with air and should consume smoothly without prematurely igniting. High innovation technologies adopted by the last decades of such engines (extremely power in a compact and very light unit) added to the need of high efficiency, imply high pressure ratios join with extremely progressed fuel systems, in many cases with modern lean-burn technologies. For this kind of engine, the LPG quality should be high since any damage to the power unit can be a source of extremely high maintenance cost and can also influence the safety of the vessel’s crew due the marine environment [128].

Presently the nature of LPG used as an outboard engine fuel can change fundamentally from one country to another. There are sure key conditions and components of the LPG fuel quality that can be considered as amazingly critical and if respected and very well controlled, they can ensure the issue free execution of a cutting-edge outboard engine. In LPG, odorants used for safety reasons contain sulfur compounds that can increase the sulfur content in LPG by 5 to 20ppm and surprisingly more if not controlled accurately.

Thus, having LPG as an acceptable competitive alternative fuel for the present gas and CNG/LNG fueled marine engines, the right "equation" can be founded on the U.S. HD5 standard, with low Sulfur (% by volume): propane: 93% min, butane: 3.5% max, propene/propylene: 3% max, other olefins: 0.5% max, sulfur: 50 ppm max (Limit embraced in numerous nations). Filtered out (not contaminated by plasticizers, rust particulates, sodium dioxide, water and other soil)

Such LPG composition can guarantee in excess of 101 Octane and can be a brilliant fuel to be adopted by marine engine manufacturers as a solid fuel for the last generation of high productivity, extremely low emission engines.

The worldwide LPG production in 2015, was 284 million tonnes, comparable to about 310 million tons of oil by energy content and is increasing by about 2% each year. In comparison, the fuel consumption in the shipping sector was assessed by IMO to be 307 million tons on average in the period from 2010-2012. The production increase has been generally significant in North America and the Middle East. The production expansion in North America in the last years can be ascribed to the significant increase in shale gas production, which has transformed the USA into a net exporter of LPG since 2012.

LPG is a suitable option vaporous fuel. It has high energy thickness contrasted to the most other oil fuels and alternative fuels and burns cleaner in the presence of air. It has high calorific value compared to other gaseous fuels and, also, high-octane number (however a low cetane number). Its high-octane number makes it reasonable for spark ignition engines (SI), while its low cetane number makes it less favorable for use in enormous extents in compression ignition engines (CI) – diesel engines.

As per its transportation, the worldwide LPG trade was around 85 million tons in 2015 (Ref: BW yearly report 2015), and subsequently around one third of the LPG is exported. LPG can be shipped by three different ship types, contingent upon how the load is put away:

1. refrigerated, normally at - 50^{O}C at close to ambient pressure.
2. semi-refrigerated, ordinarily at - 10^{O}C and 4-8 bar pressure.
3. under pressure, ordinarily at 17 bars, corresponding to the vapor pressure of propane at about 45^{O}C.

There are currently around 200 very large gas carriers (VLGCs) that can move exactly 80,000 m3 of LPG. Semi-refrigerated ships regularly have a limit of 6,000 to 12,000 m3, while compressed LPG vessels typically take 1,000 to 3,000 m3.

The transportation of LPG is covered by the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), which is focused on the protected carriage of liquids with a vapor pressure above 2.8 bar at 37.8^{O}C and applies to all vessel sizes. If an LPG carrier was to be powered by LPG, this is on a fundamental level for this particular ship type covered by the IGC Code without having to comply to the IGF Code (International Code of Safety for Ship utilizing Gases or Other Low-flashpoint Fuels). Nonetheless, the IGF Code can be utilized for additional explanation. For different vessels, the use of LPG as fuel has to be covered through alternative compliance with the IGF Code.

Worldwide LPG production is at a similar level as the fuel oil consumption in the marine area (just as the global production of LNG) and is expanding by 2–3% each year. Moreover, LPG costs in the USA have dropped comparative with crude oil costs since 2011. This indicates that there is accessibility to continuously bring LPG into the maritime area, yet not to replace fuel oil entirely.

A huge network of LPG import and fare terminals is accessible all throughout the planet to address trade needs. As of late more LPG export terminals have been developed in the US to cover the increased interest for seriously priced LPG products.

Since 2011, LPG has been sold in the USA, on an energy basis, at a discount to crude oil, however significantly higher than that of natural gas. A decoupling of LPG and oil prices, and the decrease in the cost of LPG might be attributed to the increased yield of propane from shale gas production. This improvement likewise brought about the US turning from a net shipper into a net exporter of LPG after 2011.

The drop-in oil prices since 2014 have influenced the prices of different oil-based fuels, but also natural gas, methanol, and LPG. Nonetheless, the degree to which each fuel has dropped in cost varies, and the overall situation of the fuel price has changed over the long run. For instance, LPG prices are currently at a similar level as or lower than

LNG prices in the USA. Throughout the previous few years, LPG has normally been less expensive than HFO in the USA. On the other hand, methanol has become more costly than MGO over the most recent three years.

Pure butane has about 10% higher volumetric energy density than propane yet is normally more expensive. Moreover, in outboards engines the high level of boiling over of pure butane prevents the utilization of pure butane in colder climates. Consequently, the utilization of propane existent in LPG is normal for small vessels, and butane when LPG is utilized as fuel for other vessels.

9.2 Environmental aspects of LPG [126]

LPG combustion results in lower CO_2 emissions contrasted with oil-based fuels because of its lower carbon to hydrogen ratio. Contrasted with petroleum gas CO_2 emissions are a bit higher, however a few gas engines can experience the suffer from the effects of methane slip, which increases their overall greenhouse gas emissions. Considered in a lifecycle viewpoint, LPG production is related to lower emissions than oil-based fuels or natural gas. The mix of low production and combustion emissions yields an overall greenhouse gas emission decrease of 17% contrasted with HFO or MGO. This is comparable with the ozone greenhouse gas emissions from LNG, which emphatically rely upon the measure of methane leak and could be marginally lower or higher depending on the production and combustion innovation technology.

Greenhouse gas emissions in kg CO2eq/GJ for oil-based fuels, LPG and LNG are given in the Table 12 beneath. A methane slip of 1% and an energy consumption for liquefaction of 7% are expected for LNG. Since the global warming potential for LPG and n-butane are 3 and for isobutane 4 (times the global warming potential of CO_2) contrasted with 25 for methane, any slip of un-combusted fuel through the engine would bring about less greenhouse gas emissions for LPG than for LNG.

	HFO	**MGO**	**LPG**	**LNG**
Well to tank	9.79	12.69	7.15	9.68
Tant to propeller	7770	74.40	65.50	61.80

Well to propeller	87.49	87.09	72.65	71.48
Difference to HFO	**-**	**-0.50%**	**-17%**	**-18.3%**

Table 10: Greenhouse gas emissions in kg CO2eq/GJ for oil-based fuels, LPG and LNG

Furthermore, the utilization of LPG has benefits identified with poison emissions. It virtually takes out and eliminates sulfur emissions and can be utilized as a method of consistence with low sulfur local and worldwide guidelines. The decrease of NO_X emissions relies upon the engine technology used.

For a two-stroke diesel motor, the NO_x emissions can be expected to be reduced by 10–20% contrasted with the utilization of HFO, while for a four-stroke Otto cycle motor, the normal decrease is bigger and might be underneath Tier III NO_X guidelines. To follow these guidelines, a two-stroke LPG motor ought to be furnished with Exhaust Gas Distribution (EGR) or Selective Catalytic Reactors (SCR) systems. Both solutions are commercially applicable. The use of LPG as a fuel will, as LNG, generally stay away from particulate matter and dark fossil fuel byproducts.

The natural argument to change over from fuel and diesel to LPG is strong since Cargo vessels, speed boats and fishing boats are oftentimes found on inland streams, waterways, and lakes where any type of fuel contamination can cause genuine outcomes to wildlife, fish, and the local environment.

Any spillage of gas and diesel will float on top of the water. The visual effect of a fuel spillage can be disturbing and lasting. Fuel leakages are probably going to happen during the refueling or bunkering activities. The movement of a vessel associated with a refueling hose is challenging enough, however, if the refueling is being done from a floating fuel barge, or bunkering barge, it is significantly more so. There have been a few cases including fuel spillages from fuel barges over the years and most have resulted in some type of natural harm and damage. LPG gas tanks are significantly less messy to refuel.

One more advantage of an LPG marine engine is its quietness contrasted with a diesel engine which works at high higher compression ratios leading to expanded noise.

Protection of the environment and improvement of air quality is a significant target of the regulators today. Emissions from the marine transport area contribute essentially to air contamination worldwide and in 2013 marine transport represented 2.7% of worldwide CO_2 emissions. These emissions are expected to increase by a factor of 2 to 3 by 2050 if no actions are carried out. Transportation particulate matter (PM) emissions have as of now been connected with roughly 60,000 cardiopulmonary and lungs cancer deaths annually worldwide.

Sea transport of merchandise is a moderately clean type of transportation per kilogram of material, yet additionally a productive mode requiring 2-3 grams of fuel per ton/km, contrasted with road transport by truck which is around 15 grams of fuel for each ton/km.

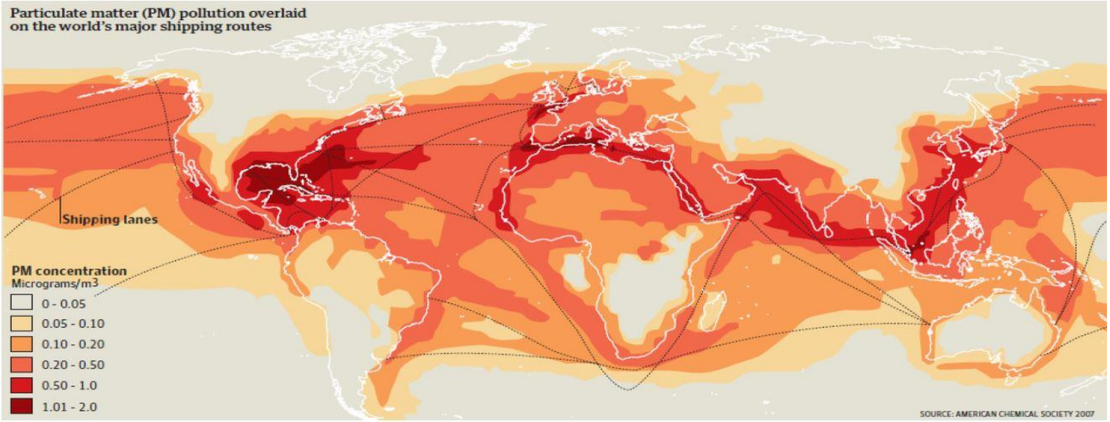


Figure 8: Source: Greener Shipping in North America. DNV [127]

At the point when vessels cross waterways, they leave behind visible "tracks" of contamination. NASA has been utilizing satellite images to gather information on ship tracks, and the results are upsetting. The above picture communicates only nitrogen dioxide (NO_2) emissions and is a complex and synthesis of information gathered by the Ozone Monitoring Instrument on NASA's Aura satellite from 2005 through 2012.

For over 10 years, researchers have noticed "ship tracks" in natural shading satellite symbolism of the sea. These bright, direct paths amidst the cloud layers are made by particles and gases from ships. They are an apparent indication of contamination from ship exhaust, and researchers would now be able to see that vessels have a subtler, practically invisible, signature as well [111].

Instrument (OMI) on NASA's Aura satellite show long tracks of raised nitrogen dioxide (NO2) levels along certain shipping routes. NO_2, is among a group of profoundly reactive oxides of nitrogen, known as NOx, that can lead the production of fine particles and ozone that harm the human cardiovascular and respiratory systems. Combustion engines, the same as those that propel ships and engine vehicles, are a significant source of NO_2 pollution.

The map above depends on OMI estimations procured somewhere in the range of 2005 and 2012. The NO_2 signal, is generally noticeable in an Indian Ocean shipping path between Sri Lanka and Singapore, appearing as a distinct orange line against (lighter) background levels of NO_2. Other shipping paths that go through the Gulf of Aden, the Red Sea, and the Mediterranean Ocean additionally show increased NO_2 levels, as do routes from Singapore to points in China. These aren't only the main occupied with shipping paths on the planet, but, also, they are the most apparent in light of the fact that vessel traffic is concentrated along narrow, well-established lanes. The Atlantic and Pacific Oceans additionally have heavy vessel traffic, yet OMI doesn't get NO_2 contamination tracks because of the fact that the shipping routes are less steady.

Furthermore, the air over the northeastern Indian Ocean is somewhat unblemished. Substantial NO_2 pollution (dim red in the guide) from urban areas and seaward penetrating activity along the coasts of China, Europe, and the United States obscures the vessel tracks that may somehow be noticeable to OMI. In the guide, the Arctic is dark on the grounds that the absence of light during the wintertime of year and continuous shadiness during the summer kept OMI from gathering usable information in that specific area.

Metropolitan regions and industrialization are not the main sources of NO_2 in the guide. Agricultural burning in southern Africa and persistent westerly winds make a raised band of NO_2 that stretches from southern Africa to Australia. (In central Africa, easterly winds push pollutants from fires toward the Atlantic, keeping NO_2 levels nearly low over the northern Indian Ocean.) Lightning, which produces NOx, likewise contributes to background NO_2 levels.

Research suggests that shipping represents 15 to 30 percent of worldwide NOx emissions; researchers are utilizing satellite observations to lessen the vulnerability in such estimates.

Inside Europe, 40,600 km of inland waterways and intra-EU maritime transport are utilized with inland navigation representing 1.6 % of final energy utilization in the transport sector.

Emissions from this sector contribute to 1-7% of ambient air PM10 levels, 1- 14% of PM2.5, and at least 11% of PM1 and 4-6% of PM2.5 in Seattle. In a few non-European harbors, contributions have been reported for example of <5% of PM2.5 in Los Angeles Commitments to surrounding NO_2 levels range between 7-24%, with the highest values being recorded in the Netherlands and Denmark. In numerous waterfront spaces of Europe, it has been assessed that, vessels will be responsible for over half of sulfur release in 2020, which could add to the formation of acid rain. This is mainly on the grounds that traditionally the shipping business has used fuels with high sulfur content, purchased at a price lower than that of crude oil.

The future of marine engines to guarantee sustainability and worldwide acknowledgment, requires the improvement of systems that diminish the reliance on oil and limit the emission of greenhouse gases. Decarbonization, reliability and safety are the drivers for marine market advancement and development. Complying with environmental standards and requirements will entail however exorbitant technologies, for which fleet and different operators might be unwilling to address the cost.

The huge price advantage against diesel and plentiful supplies of LPG reinforces the idea that LPG marine engines can play a significant role as a significant part of a perfect fuel portfolio for the years to come towards reductions of GHGs, NOx and PM emissions and almost zero emissions objectives in specific combined with hybrid technologies.

9.3 Safety [125]

Safety issues and guidelines for the utilization of LPG should be tended to before this turns out to be more acceptable by the maritime industry.

A significant property of LPG is that when in vapor form, it is heavier than air and when it leaks it generally tumbles to the ground. If an LPG leak in a vessel is not noticed, it will escape to the engine room floor or bilge.

The favored method of storing LPG for use as propulsion fuel is in a compressed tank at ambient temperature. Storage in a semi-refrigerated tank made of less expensive steel types than for LNG is also possible, yet all together for such an arrangement to be adequately solid, back-up frameworks should be set up to guarantee low temperature in the tank. This makes compressed tank storage a more reliable, affordable, and simple arrangement.

LPG has a higher density than air and any spillage will gather in lower spaces, requiring an alternate way to deal with leak detention and ventilation in case of leaks. LPG is a low-flash point fluid, and when utilized in a high-fire-risk space of the vessel with a consistent personnel presence, for example in the engine room, a double-walled pipeline should be used as an optional regulation. Hydrocarbon sniffers will recognize any spillage and contain the fuel inside the optional regulation before it arrives at regions where people are present. Double-walled pipelines should be used beneath the deck line.

The auto ignition temperature for LPG (490°C) is lower than for LNG (580°C), which might require a lower surface temperature close to electrical gear. Contrasted with LNG, LPG has less difficulties identified with temperature since it is not kept at cryogenic temperatures yet then again it has difficulties identified with the higher density as a gas and a lower ignition range, with a lower explosion restraint of about 2%. The difficulties are unique, however in general, the safety management is presumably to some degree less complex for LPG than for LNG.

The advancement of any new innovation requires highest consideration and thought of safety suggestions and particularly so if the new innovation includes motors and hardware, apparatus, or potentially vessels that utilization LPG as a fuel.

LPG, same as any other fuel, can be totally safe as long as the equipment is planned effectively with all security perspectives considered and the activity is similarly completed in a similar way. New innovations and technologies require intensive evaluation of all potential safety risks.

Especially in the marine environment, three primary variables should be thought of: Corrosion issues, vibration, and constant movement of the vessel. The use of corrosion safe composites and stainless steel, galvanizing and suitable coatings are normally utilized in the marine environment. The extra expense of using these materials will be outweighed by the potential harm caused by not using them and the need to replace components. Moreover, the considerable effect of failure when out on the water could have disastrous effects.

As to safety issues, the International Code of Safety for Ships utilizing Gases or other Low-flashpoint Fuels (IGF Code) was adopted by the Maritime Safety Committee (MSC) by goal MSC.391(95), to give a worldwide standard for the safety for ships using low-flashpoint fuel, other than ships covered by the IGC Code. The IGF Code is made obligatory under corrections to sections II - 1, II - 2 and the appendix to the annex of the International Convention for the Safety of Life at Seas (SOLAS), 1974, that were adopted by the MSC at a similar session, by resolution MSC392(95) (passage into power: 1 January 2017).

The adoption and enforcement of the IGF Code was the result of more than 10 years of work by a few IMO bodies, beginning with the endorsement by MSC78 (May 2004) of a work thing on "Development of provisions for gas-fueled ships". Following the adoption by MSC86 (June 2009) of the Interim Guidelines on safety for natural gas fueled engine establishments in ships (resolution MSC.285(86)), MSC 87 supported the augmentation of the scope of the work on advancement of arrangements for gas-fueled vessels to incorporate vessels fueled by low-flashpoint liquid fuels. The current form of the IGF Code incorporates guidelines to meet the functional necessities for natural gas fuel. Guidelines for other low flashpoint fuels will be added as, and when, they are developed by the Organization.

This Code gives a worldwide norm to ships utilizing low-flashpoint fuel, other than ships covered by the IGC Code. The essential way of thinking of this Code is to provide obligatory arrangements for the arrangement, establishment, control, installation and checking of the machinery, equipment and systems utilizing low-flashpoint fuel to limit the risk to the vessel, its crew and, furthermore, the climate and environment, having respect to the idea of the fuels involved.

10. Conclusion - Discussion

Consequently, IMO has developed the ambitious target of a minimum 50% reduction in greenhouse gas (GHG) emissions by 2050. Shipowners have alternative fuel options to help them meet IMO’s ambitions, each with its own advantages and challenges. First and foremost, LNG has a competitive fuel price, it is available globally, safe to handle and there are available infrastructure technologies, but has increased CAPEX. Furthermore, hydrogen is a long-term solution, and it enables zero-emission and can be produced near ports, it has also increased CAPEX, it has high fuel price and safety measures should be taken into serious consideration. Moreover, cold ironing has great environmental effects but the costs for technological investments and infrastructure are outrageous. Additionally, ammonia is a long-term solution and a zero-carbon emission fuel, but still harmful for the human health on the grounds that it is toxic when leaked. Also, it is an expensive fuel with increased CAPEX. Methanol is easy to handle, but there are concerns about its flammability as well as its increased cost and CAPEX. Last but not least, LPG is a clean fuel, really safe to handle and is world widely available.

There are ways for decision-makers in maritime explore these continuous changes and ensure that they are best situated and ready for what's to come. Actually, numerous shipping companies and organizations cannot understand the advantages from such investments in the short term, yet the investors who get ready for the future could understand a huge and sustained competitive advantage as a result of their foresight. To do as such, maritime business pioneers ought to have an essential understanding of the present and future possibilities for changes that will occur, how the innovation works, the dangers implied, the issues that can be tackled and how they should prepare to take advantage of the capability of the new marine fuels.

The work featured in this paper shows that a comparative progress in shipping is possible and those that are intense to make a move and to understand the potential outcomes and advantages of the new trends in marine fuels could acquire a benefit through their adoption and those with a longer-term out term outlook could see their speculation pay off. There are clear uncertainties identified with how things will develop to 2050. In any case, given the lifetime of vessels, a prudent financial investor would cautiously consider the dangers of proceeding with the same old thing. Our research reveals some key insights of knowledge for shipowners that are considering about planning for a carbon free future in the short, medium and long term.

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