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"The IMO2020 regulation implementation dilemma"

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Διπλωματική Εργασία

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Abstract

Since MARPOL annex VI was adopted in 1997 it has been evident that the shipping industry has been in line with controlling, reducing and gradually eliminating emissions that are harmful to the environment and human health. Technological improvements gave the green light for the revision of annex VI in 2008 and the strengthening of the limitation of the emissions' sulfur content to 3,.5% globally from 2012 and a further global limitation of 0.5% enforceable in 2020, while complete decarburization of the industry still remains a goal until 2050.

With 2020 right around the corner there has been no topic more discussed amongst shipping executives than how each company will choose to comply with the new regulation while remaining viable, sustainable and still profitable to its shareholders. While most ship-owners remained reluctant towards committing to a single way of compliance, either due to the high cost of new technologies or them waiting to see the strategies of their competition in order to create or maintain competitive advantage, it gradually became clear that as 01.01.2020 draws closer a decision would have to be made.

At this point, ship-owners have either chosen or will have to choose between installing the rather new and expensive technology of scrubbers, the even more expensive dual fuel engine, which provides the option of consumption of LNG, or consuming low sulfur fuels, that be either distillate fuels, or the new residual fuel that has been a very recent project among refineries and currently still has many questions to be answered.

While there is currently no rule of thumb of which option would suit each company, each of the above solutions creates separate challenges, comes with different costs and needs in financing, require different training for shore and offshore personnel and provide benefits to the managing companies, thus will be analyzed and presented in detail.

Key words: IMO, scrubbers, LNG, Fuel, sulfur cap.

Περίληψη

Από τη στιγμή που υιοθετήθηκε το πρωτόκολλο VI της Διεθνούς Σύμβασης για την Αποτροπή της Θαλάσσιας Μόλυνσης από τα Πλοία (MARPOL) το 1997, είναι εμφανές ότι η ναυτιλιακή βιομηχανία έχει ευθυγραμμιστεί με τον έλεγχο, τη μείωση και σταδιακά την εξάλειψη των εκπομπών αερίων, που είναι επιβλαβή για το περιβάλλον και την ανθρώπινη υγεία. Η τεχνολογική πρόοδος έδωσε το πράσινο φως για την αναθεώρηση του πρωτοκόλλου VI το 2008 και την αυστηροποίηση σε σχέση με τα όρια των εκπομπών αερίων με περιεχόμενο θείου από 3,5% που ίσχυε το 2012 σε 0,5% το 2020, ενώ η πλήρης απαλλαγή από τα ορυκτά καύσιμα παραμένει ο βασικός στόχος μέχρι το 2050.

Με το 2020 να βρίσκεται προ των πυλών, δεν υπάρχει πιο πολυσυζητούμενο θέμα μεταξύ των στελεχών της ναυτιλιακής βιομηχανίας, σχετικά με το πώς κάθε εταιρεία θα επιλέξει να εναρμονιστεί με το επερχόμενο κανονιστικό πλαίσιο, παραμένοντας βιώσιμη, αειφόρα αναπτυσσόμενη και συνάμα επικερδής για τους μετόχους της. Καίτοι οι περισσότεροι πλοιοκτήτες και μανατζερ παρέμεναν διστακτικοί στο ενδεχόμενο να επιλέξουν ένα και μόνο μοντέλο εναρμονισμού στο νέο πλαίσιο (είτε λόγω του ότι οι νέες τεχνολογίες είναι αρκετά δαπανηρές, είτε επειδή ανέμεναν να δουν τη στρατηγική των ανταγωνιστών τους προκειμένου να δημιουργήσουν ή να διατηρήσουν ανταγωνιστικό πλεονέκτημα έναντι αυτών), είναι πλέον προφανές ότι μια απόφαση πρέπει να ληφθεί ενόψει της έλευσης της 01.01.2020.

Στο σημείο αυτό οι πλοιοκτήτες έχουν είτε ήδη διαλέξει ή θα πρέπει να διαλέξουν μεταξύ της εγκατάστασης της μάλλον νέας και ακριβής τεχνολογίας των συστημάτων καθαρισμού καυσαερίων των πλοίων (ή απλούστερα scrubbers), της ακόμη ακριβότερης λύσης μηχανών διπλής καύσης, η οποία παρέχει την επιλογή κατανάλωσης είτε φυσικού αερίου (LNG), είτε αποθειωμένων καυσίμων (LSFO), τα οποία καύσιμα είτε θα προκύπτουν ως απόσταγμα διύλισης, είτε ως νέο καύσιμο ως υπόλειμμα της απόσταξης, ένα πρότζεκτ νέο μεταξύ των διυλιστηρίων περί το οποίο πολλές ερωτήσεις μένουν να απαντηθούν ακόμη.

Παρά το γεγονός ότι αυτή τη στιγμή δεν υπάρχει κανόνας σχετικά με το ποια επιλογή ταιριάζει καλύτερα σε κάθε εταιρεία, καθεμία από τις παραπάνω επιλογές δημιουργεί και διαφορετικές προκλήσεις, κόστη - χρηματοδοτικές ανάγκες, απαιτήσεις για εκπαίδευση προσωπικού στα πλοία και τις εταιρείες, αλλά και επιφέρει προνόμια στις εταιρείες, οδηγώντας σε ανάγκη αυτοτελούς μελέτης τους.

Λέξεις κλειδί: Διεθνής Ναυτιλιακός Οργανισμός, Scrubbers, Φυσικό Αέριο, Καύσιμα, Όριο εκπομπών Θείου.

Table of contents

Abstract iv

Περίληψη v

Table of contents vi

Introduction 8

Chapter 1: The current regulatory status 10

1.1. The International Maritime Organization (The IMO) 10

1.2. Environment-GHG SOx and NOx emmissions. 11

1.3. MARPOL Annex VI and the ECA zones 15

Chapter 2: Residual fuel oils: The past and present of the shipping industry's driving force. 17

2.1. Crude oil as a base material and refining process 18

2.2. Bunkering procedure and standardization of quality specifications 19

Chapter 3: 2020 and the road ahead: The option of distilled and new fuels 20

3.1. A multi-fueled future for shipping 20

3.1.1. Ultra-Low Sulphur Fuel Oil 21

3.1.2. Very-Low Sulphur Fuel Oil 21

Chapter 4: A mix of new and old: Exhaust Gas Cleaning Systems (Scrubbers) 23

4.1. Scrubber types and functions 23

4.1.1. Open-loop –seawater- scrubber type 24

4.1.2. Closed-loop scrubber type 26

4.1.3. Hybrid Scrubbers 28

4.1.4. Dry Scrubbers 29

4.2. Challenges presented by the installment and use of scrubber technology 30

Chapter 5: Does Liquefied Natural Gas hold the solution for the future of marine propulsion? 35

5.1. LNG properties and viability 36

5.2. LNG use drawbacks 37

Chapter 6: 2020: The beginning of the multi-fueled future of the shipping industry 40

6.1. Fuel cells and Hydrogen 40

6.2. Ammonia usage 41

6.3. Dual fuel engines and methanol usage 41

6.4. Bio-fuels 43

Conclusions 44

References 51
Bibliography: 51
Figures: 52
Articles / Journals: 53

Introduction

As in every other heavy industry, shipping is formed and shaped by several sets of laws and regulations set by either flag states in their territorial waters or the international institutions. This legal framework is dynamic and constantly changing and updated, in order to create and maintain the high quality standards of the industry in terms of safety for the lives of those onboard the thousands of vessels carrying trade goods across the oceans, in terms of protection for the marine environment, as well as the global ecosystem and finally in terms of the necessary quality and reliability that the shipping industry is already proud of. This ever-changing regulatory framework, which follows trends and necessities often dictated from factors residing outside the limited borders of the specialized shipping industry (e.g. financial trends regarding money-laundering, workforce and demographic trends etc.), is sometimes considered a bit too strict or even harsh by those who are called to comply with it. It is quite common for managers or owners of vessels to be on the complaining side, when major reforms in environmental laws are underway, especially due to the fact that they consider that these changes work against their operating and financial interests and in general against the trading activity worldwide.

The particular subject was chosen by the writer, as currently there is no other matter in the recent years troubling shipping companies as much as how they will meet the requirements of the Annex VI of MARPOL, coming into force from 01/01/2020 often mentioned as IMO 2020. The so-called “Sulphur Cap” on the allowed emission of Sulphur content in the gas emissions of a vessel is a matter that troubles each and every owner or manager of vessels around the world, due to the horizontal character of its implementation. But it does not stop there, as the implications of such a major change in the fuel used by the vessels that carry 90% of the volume of the global trade (United Nations Business-Action HUB, 2019) will undoubtedly affect the interests of charterers around the world –especially when they themselves carry the fuel expense burden in cases of trip/time/bareboat vessel charters-. The chain effect unleashed by a change in the expenses in such a crucial and fundamental element of the transport chain will be very important and much has to be done in analyzing data regarding the potential options the players in the market have in order to remain on the profit and viable/sustainable side.

Ship owners, managers and charterers have had almost a decade to review their fuel strategy and decide which of the options technologically available to them they are going to follow in order to comply with the sulfur cap in their vessels’ emissions, evaluating at the same time all the data regarding the investments needed, their financial impact and other issues regarding vessel operation and performance. At the same time other major stakeholders of the shipping industry such as refineries and fuel suppliers are facing the challenge of meeting the demand and quality requirements for the new fuel types, compliant with the regulation, while local and global authorities will have to enforce the new regulations while remaining realistic and ensuring that the minimum possible obstacles will be posed in the trading activity.

The first chapter of this thesis will briefly explain what the role of the IMO is, how conventions are developed and come into force. Furthermore, the effects of ship emissions to human health and the environment will be presented, as well as information about MARPOL Annex VI and its crucial elements, the time it came into force and what is the purpose of it. Finally there will be a short presentation of the Emission Control Areas and localized efforts to limit sulfur and greenhouse gas emissions prior to the new regulation coming into force.

In the second chapter, residual fuels will be reviewed. The current bulk of fuels the majority of ships consume, their main properties and supply, as well as the way they are produced from the raw material of crude oil in the refineries and information regarding their special features.

In the third chapter the first option, that of consumption of distillate fuels will be examined, their properties and challenges in use, as well as the newly developed blended fuels based on both residual and distillate fuels.

In the fourth chapter, the second option of scrubbers will be reviewed. Different types of scrubbers will be analyzed as well as their properties, advantages and disadvantages once installed.

In the fifth chapter, the long-existing fuel option of LNG will be described and examined as a means of propulsion which appears more environmentally-friendly, as far as CO2 emissions are concerned.

In the sixth and final chapter, information combined with thoughts will be given on other options, not as popular as the previously mentioned, as well as technologies that are currently being developed and are expected to provide viable solutions towards emission control and decarburization in the near future.

The objective of the analysis of each separate option is to provide a complete but brief comparative guide of the options shipping companies have available to choose from in order to develop the most beneficial and viable fuel strategy to follow in the coming years considering the advantages and disadvantages of each one, as well as the potential disruptions in availability, supply and prices.

<u>Chapter 1:</u> The current regulatory status

1.1. <u>The International Maritime Organization (The IMO)</u>

The International Maritime Organization was known until 1982 as the Inter-Governmental Maritime Consultative Organization (IMCO) and is a specialized agency responsible for regulating shipping. The IMO was established following agreement at a UN conference held in Geneva in 1948 and the IMO came into existence ten years later, meeting for the first time in 1959. Its headquarters are in London, United Kingdom, and it currently has 174 member states and 3 associate members.

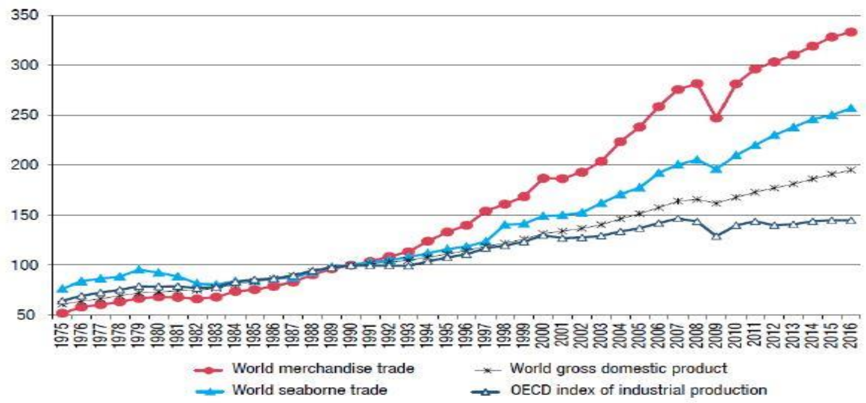
As a specialized agency of the United Nations, IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented issuing guidelines and assisting all stakeholders –such as flag states, classification societies and other institutions- towards this direction.

In other words, its role is to create a level playing-field so that ship operators cannot address their financial issues by simply cutting corners and compromising on significant matters such as safety, security and environmental performance. This approach also encourages innovation and efficiency.

Shipping is a truly international industry, and it can only operate effectively if the regulations and standards are themselves agreed, adopted and implemented on an international basis. And IMO is the forum at which this process takes place.

Figure 1: Global GDP ratio to Global Seaborne Trade and Global Merchandise Trade

Figure 1.1. Organization for Economic Cooperation and Development index of industrial production and world indices: Gross domestic product, merchandise trade and seaborne shipments, 1975–2016 (1990 = 100)



Sources: UNCTAD secretariat calculations, based on data from OECD, 2017; United Nations, 2017; *UNCTAD Review of Maritime Transport*, various issues; World Trade Organization, 2012.
Note: Index calculations are based on GDP and merchandise trade in dollars, and seaborne trade in metric tons.

Source: UNCTAD, (2017), 'Review of Maritime Transport 2017'

International shipping transports approximately 90 per cent of global trade to people and communities all over the world. Shipping is the most efficient and cost-effective method of international transportation for most goods; it provides a dependable, low-cost means of transporting goods globally, facilitating fast, frequent and reliable transport for almost any cargo to almost any foreign destination at a predictable charge whether it is bulk shipping or containerized the one discussed about (Stopford, 2009).

IMO measures cover all aspects of international shipping including ship design, construction, equipment, manning, operation and waste / ballast water disposal, ensuring that this vital sector remains safe, environmentally sound, energy efficient and secure.

Shipping is an essential component of any program for future sustainable economic growth. Through IMO, the Organization's Member States, civil society and the shipping industry are already working together to ensure a continued, strengthened and ever-growing contribution towards a green economy, as well as growth in a sustainable and viable manner. The promotion of sustainable shipping and sustainable maritime development is one of the major priorities of IMO in the coming years (IMO, 2019).

1.2. Environment-GHG SOx and NOx emmissions.

Although shipping is considered to be the most effective way of cargo transportation compared to road transportation and aviation in terms of fuel consumption and usage of economies of scale, thus resulting in a cost-efficient means of goods' transportation around the globe, the gas emission quality of ships is significantly worse than that of their counterparts due to the lower quality of fuel that is widely used in sea transportation (High Sulphur Fuel Oil or HSFO), therefore having adverse consequences to the environment.

The main components of the emissions of a diesel engine on board a ship are carbon dioxide (CO_2), oxygen, water, and nitrogen, while sulphur oxides (SOx), nitrogen oxides (NOx), carbon monoxide, particulate matter and hydrocarbons.

Despite significant improvement in the quality and efficiency of ship engines in the recent years, the emissions from the ships of the global fleet -whose numbers are constantly increasing over the last decades- engaged in international trade in the seas surrounding Europe (the Baltic, the North Sea, the north-eastern part of the Atlantic, the Mediterranean and the Black Sea) are estimated to an amount of approximately 1.6 million tons of sulfur dioxide and 3 million tons of nitrogen oxides a year in 2013. In addition sea transportation produces 2.7% of global CO_2 (Buhaug et al., 2009), 15% of man produced NOx and 4-9% of SOx.

Gas emissions from ship funnels are considered to cause the death of 50.000 people each year in Europe and are the cause of 22 billion euros in health cost in the North Sea and Baltic countries alone, a number however that is expected to significantly drop to 14.1 billion euros in 2020 due to the newly imposed stricter sulfur cap regulation to come in force (Ågren C., 2013).

Often confused and treated as one and the same problem, hazardous emissions from ship engines cause separate effects to the environment and require separate and significantly differentiated strategy and regulation. It is crucial at this point to understand the distinction between the greenhouse gases and the SOx-NOx.

Greenhouse gases have the property of absorbing infrared radiation (net heat energy) emitted from Earth's surface in order to escape back to the outer layers of the atmosphere -and eventually space- and redirecting it back, thus contributing to the greenhouse effect. Carbon dioxide, methane, clouds and water vapor are the most important greenhouse gases accounting for approximately 95% of the overall greenhouse gases in the atmosphere (Schmidt et al., 2010). Greenhouse gases have a profound effect on the energy budget of the Earth system despite making up only a fraction of all atmospheric gases. Concentrations of greenhouse gases have varied substantially during Earth's history, and these variations have driven substantial climate changes in a wide range of time frames of the planet's history. In general, greenhouse gas concentrations have been particularly high during warm periods and low during cold periods.

The initial IMO strategy to control GHG, which is scheduled to be revised in 2023 and then reviewed in 2028, contains an overall vision for gradual decarburization, the

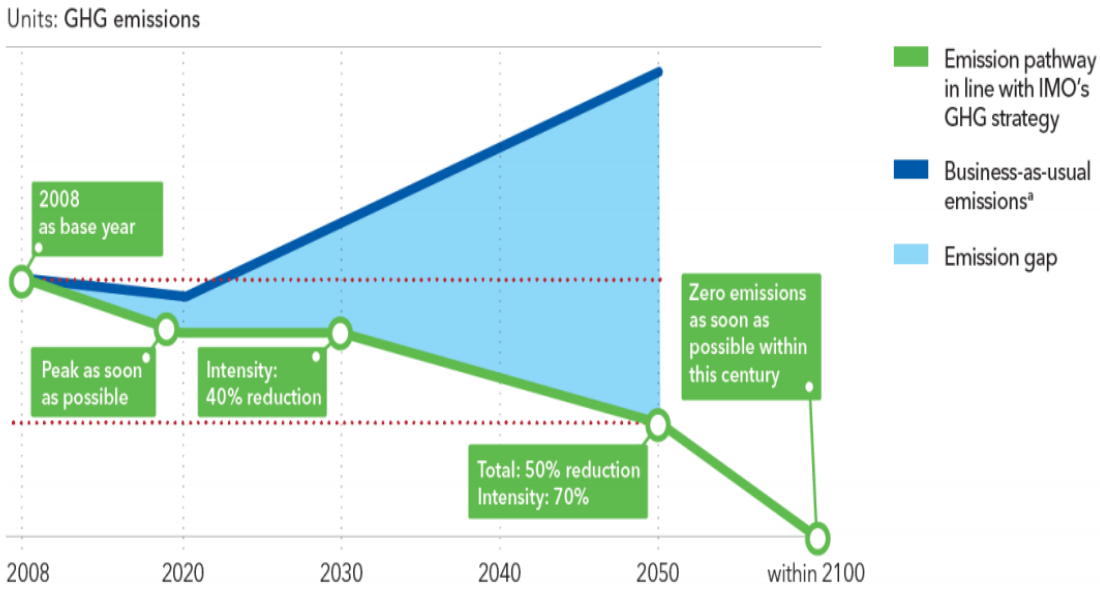
GHG reduction targets up until 2050; a list of short, middle, and long term measures to meet these targets; difficulties and ways of achieving the targets, and finally criteria for future review. Vision of the resolution is a qualitative description of IMO's ambition. It states that "IMO remains committed to reducing GHG emissions from international shipping and, as a matter of urgency, aims to phase them out as soon as possible in this century."

Figure 2: Candidate measures included in IMO's initial GHG strategy

Type	Years	Measure	Target	Current status
Short-term	2018-2023	New Energy Efficiency Design Index (EEDI) phases	New vessels	-10% in 2015 -20% in 2020 -30% in 2025
		Operational efficiency measures (e.g. SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Existing fleet improvement program	In-service vessels	—
		Speed reduction	In-service vessels	—
		Measures to address methane and VOC emissions	Engines and fugitive emissions	—
Mid-term	2023-2030	Alternative low-carbon and zero-carbon fuels implementation program	Fuels/new and in-service vessels	—
		Further operational efficiency measures (e.g. SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Market-based Measures (MBMs)	In-service vessels/fuels	—
Long-term	2030+	Development and provision of zero-carbon or fossil-free fuels	Fuels/new and in-service vessels	—

Source: Rutheford D., Comer B., (2018), 'The International Maritime Organization's Initial Greenhouse Gas Strategy'

Figure 3: IMO Greenhouse Gas Emission Reduction Strategy



Source: Longva T., (2019), 'Maritime Energy Sources For The Future'

The SOx and NOx are the result of Marine fuel burned inside the combustion chamber by the correct mixture of fuel and air in the presence of heat or an ignition source – such as the compression stroke of a piston-. Nitrogen reacts with oxygen under certain engine operating conditions to form Nitro-gen oxides (NOx) emissions. Sulphur oxides (SOx) emissions are caused mainly due to the presence of a Sulphur compound in the fuel. Smoke containing Sulphur oxides emitted by the combustion of marine fuel will often oxidize further, forming sulphuric acid, which is a major contributor to acid rain. SOx emissions also contribute to the formation of secondary inorganic aerosol gases – fine particulates that are harmful to people. The main Sulphur oxides are Sulphur dioxide (SO2) and Sulphur trioxide (SO3) together commonly referred to as SOx. Production of Sulphur dioxide is significantly larger than that of Sulphur trioxide, production of which requires specific reaction conditions, especially pressure and temperature.

Sulphur oxides and especially Sulphur dioxide are hazardous for the environment (forests, aquatic life, biodiversity, crops etc.), as well as the human health. While large concentration or SO2 is required to cause severe damage to the human body, sulphur dioxide is considered one of the most dangerous for the human health among hazardous gases in the atmosphere, causing a variety of health problems that mostly affect the human respiratory system. Acid rain changes the pH of soils in forests creating toxins and destroying the nutritious minerals essential for trees and vegetation. Acidification takes place also in the lakes and seas, increasing the pH, lowering an ecosystem's biodiversity.

1.3. MARPOL Annex VI and the ECA zones

In the 29th meeting of the Marine Environment Protection Committee (MEPC), which came in session on March 1990, it was the first time that the atmospheric pollution caused by the emissions of the vessels of the global fleet was addressed as a major problem. The matter was set as a high priority one for the next meeting and it was agreed that member states would research thoroughly the problem. After long debates and presentation of contradictory researches in the 32nd session of MEPC, the result was a decision to limit the sulphur content of the fuel oil used by the merchant fleet to an amount of 3-5% of its overall weight. In the 36th and 37th session of MEPC Annex VI of MAPOL treaty was completed and adopted, coming eventually into force in May 2005 (IMO, 2019). Annex VI introduced a number of drastic changes to the regulatory framework regarding the air emissions of vessels.

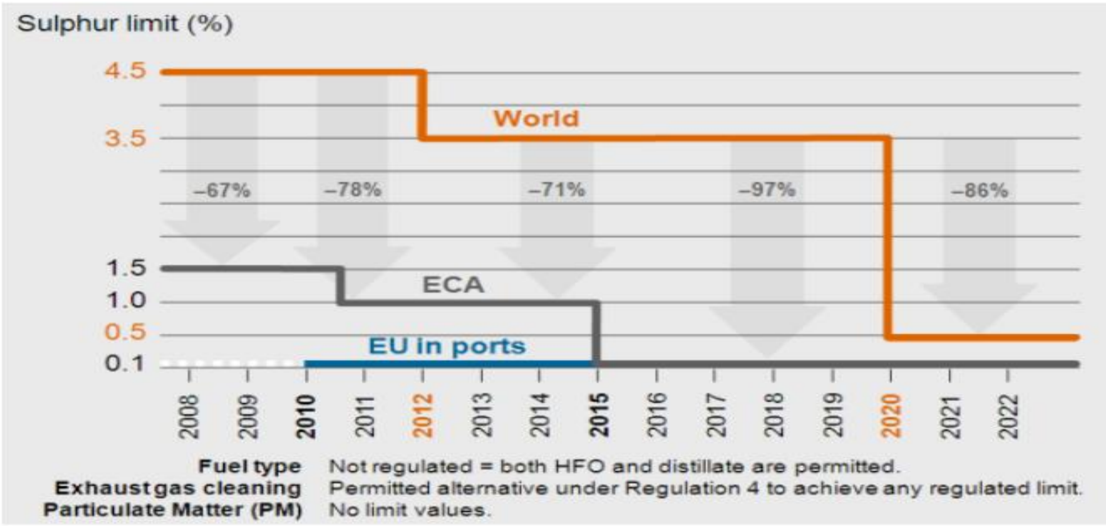
More specifically, it set limits in the emission of sulphur oxides (SOx) and nitrogen oxides (NOx) and banned the emission of gases that harmed the ozone layer. However, the most drastic change in the Annex was the creation of SECA zones (Sulphur Emission Controlled Areas). This was due to the environmental sensitivity of those areas, as well as the large number of ships that increased the impact of gaseous pollutants on human health. The first such zone was created in the Baltic Sea region, while in 2005 North Sea was also registered under the SECA status (IMO, 2019). Resolution MEPC 190 (60) has enacted the North American ECA covering the US and Canadian coasts, with effect from 1/8/2012.

In addition, Annex VI included Regulation 14, which set a world-wide 4.5% ceiling on sulfur content of fuels. This percentage was expressed as a percentage of weight and was even lower for SECA regions, at 1.5% (IMO, 2019). Furthermore, IMO Regulation 14 sets out the procedures to be followed when choosing fuel change-over as a compliance strategy in the organization's regulations. It is clearly stipulated that the ship must have completed HSFO rotation with compatible fuel (usually MGO) before entering the ECA zone. Accordingly, switching of MGO to HSFO should start after exiting the ECA zone. In both cases the quantities of compatible fuels as well as the day, time and location of the ship in the ship's logbook should be recorded (IMO, 2019).

In October 2008 in MEPC 58 the IMO revised Annex VI of MARPOL. Under the new limits, the maximum permitted sulphur content of fuels would drop to 3.5% worldwide since 1/1/2012, while ECA zones had already been set at 1% since 1/1/2010. The IMO further amended the regulations as of 1/1/2011, imposing a sulphur limit of 0.10% within ECA zones and 0.50% worldwide starting on 1/1/2020. The latest limit however, would depend on the results of the IMO study on the availability, efficiency and compliance of low sulphur fuels, which would be completed by 2018.

The following tables depict the limits in sulfur for ships' emissions' content throughout the years:

Figure 4: IMO Sulphur limits for years 2008-2020



Source: Almeida R., (2012), 'Have the IMO and the International Chamber of Shipping Overlooked the Obvious?'

Figure 5: Evolution of sulphur content of marine fuel over the years

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

Source: International Maritime Organization, (2019)

On top of the IMO's efforts to limit the contents of ship emissions in sulfur, the European Union came in par with directive 1999/32 of the European Committee which sets a limit of 3.5% to sulfur content of emissions, unless a scrubber is installed. Furthermore, directive 1999/32 EC sets a limit of 0.1 % of sulfur content to distillate fuels and forbids the consumption of fuels with sulfur content higher than 0.1% for ships that enter European ports and ECA zones coming into force on the 01/01/2015. It also contains a time margin regarding fuel change for ships entering and exiting port areas. Directive 1999/32 was ratified by the IMO and was renewed with 2012/33 EC, which includes the lower limit of sulfur content of 0.5% worldwide, which would come into force on the 01/01/2020 (EU, 2012). The most recent revision of directive 1999/32 EC is with the directive 2016/802, which includes Annex VI regulation 14 of MARPOL and member states ensure that in their territorial waters fuels with sulfur content above 3.5% will not be used, unless vessels are equipped with the proper closed-type scrubber system from 18/06/2015 (EU, 2016)

In the United States, the California-State-Regulation under the title "Fuel Sulfur and Other Operation Requirements for Ocean-Going Vessels within California Waters and 24 Nautical Miles of the California Baseline" (or, the Ocean Going Vessel (OGV) Fuel Regulation) has been enforced since July 2009 and was designed to provide significant air quality benefits by requiring ships to use cleaner, low sulfur marine distillate fuel in their main engines, auxiliary engines and auxiliary boilers. The OGV Fuel Regulation does not apply to propulsion boilers. Fuel Requirement Effective Date ARB's California OGV Fuel Requirement The California Air Resource Board, CARB, regulations do not specifically allow the use of anything other than low sulfur distillate fuel for compliance. However, CARB has permitted the use of ECA compliant non-distillate low sulfur fuel or equivalent alternative emission control technologies under 'Research Exemption' criteria, which are applicable during the sunset review period. This is the period during which CARB staff will evaluate the emission reductions achieved by the ECA regulations and compare them to the emissions reductions achieved by the California OGV fuel regulation. In all cases, the vessel owners and operators must notify the CARB authority to agree to this 'Research Exemption'. The notification is to be sent prior to initial entry into regulated California Waters.

In the People's Republic of China (PRC) – China has developed local air emissions regulations applicable to the Pearl River Delta, Yangtze River Delta and Bohai Rim Area under "The People's Republic of China Air Pollution Prevention Law". The regulations apply to ships navigating, at berth and operating within the emission control areas which extend out to 12 nautical miles from the coastline. The regulations implement a phased date approach and are focused on the application of international requirements and controlling emissions from ships at berth for more than two hours. Beginning 1 January 2017, ships at berth must use fuel with a maximum sulfur content of 0.50% and starting 1 January 2019 this fuel limit is also applicable within the PRC Marine Emission Control Areas. However, some of the local authorities among these three regions implemented the regulations earlier than the originally declared date by separate instructions. The use of alternatives such as shore power connections or exhaust gas cleaning systems (scrubbers) is permitted. Hong Kong Special Administrative Region of the PRC - The regulation for air pollution control for ocean going vessels (OGV) at berth was first enforced on 1 July 2015. Vessels are to use fuel oil, not exceeding 0.50% sulfur, while at berth excluding the first and last hour of the berthing period. The regulation applies to a vessel of 500 gross tonnage and above. Hong Kong recently decided to align with the newly adopted China ECA regulations, noted above.

In Australia, the Australian Government announced on 1 December 2016 that all cruise ships berthing at Sydney Harbor may burn fuel with a maximum sulfur content of 0.10% or utilize an alternative method to deliver the same outcome. (ABS 2019)

<u>Chapter 2:</u> Residual fuel oils: The past and present of the shipping industry's driving force

Maritime transportation of goods is a concept that exists for approximately five millennia and is interwoven with the overall trading activity of nearly all historic civilizations. Driven forward by rowers, the wind or steam shipping has assisted a lot in the evolution of human societies through the centuries. However, the catalyst for the creation of an industry so massive, efficient and reliable regarding the transportation of goods was the invention of the internal combustion engine at the dawn of the 20^{th} century, unveiling a lucrative future ahead. Using at first steam produced out of burning coal and later heavy fuel oil, ships became the most efficient means of transportation for passengers and commodities. With the technological advancements during the 20^{th} century, vessels around 1950-1960 were mostly equipped with diesel engines constantly evolving and becoming more efficient in their performance. In this chapter we shall briefly present the main characteristics of the main source for marine propulsion, fuel oil.

2.1.Crude oil as a base material and refining process

The main raw material for the creation of all types of fuel oil is the valuable resource called crude oil. Crude oil is a mixture of various hydrocarbon elements with different molecular structure such as Methane, Ethane, Propane or Decane. There are also formations of nitrogen, oxygen and water within the mixture, as well as certain metal elements and gases like carbon dioxide and helium. Crude oil can be classified in three different categories depending on their chemical composition: 1) Paraffinic, 2) Napthenic, 3) Aromatic, with the first two being more widespread in the world and more appropriate for use in diesel or gasoline engines (Society of Petroleum Engineers, 2015).

In order to transform crude oil of any chemical composition into useful products that can be used in the actual economy (e.g. Liquefied Petrol Gas, Gasoline, Kerosene, Diesel and Fuel oil etc.), refining process must take place in specialized industrial centers called refineries. During the crude oil refinement process hydrocarbons are separated and converted into final products through further processing or commingling. The final products are categorized from lighter to heavier, with the first category including gasoline, naphtha (heavy or light), kerosene and residential heating diesel, while in the latter category one can include lubricating oils, heavy fuel oils, tar and asphalt.

During the 20^{th} century and the unprecedented rise in the living standards, especially in the western Europe, the United States and far-east Asia, the requirements for more light and “noble” products was ever-growing, thus leading to the introduction of new methods in the crude oil refinement process. In the older times without the new methods, half of the crude oil undergoing refining process was unable to turn into light products, eventually being used as a “good quality” heavy fuel oil. Nowadays with the new methods used, a significant amount of those heavy products is converted to lighter ones (such as diesel into gasoline), leaving gradually hydrocarbons of the worst quality to be used as a fuel oil in the shipping industry.

2.2.Bunkering procedure and standardization of quality specifications

As fuel oil became the main means of propulsion after the 1960s, the issue arising from the new bunker technology regarding its compliance with both the existing machines and matters of environmental nature became more and more concerning. Bunkering procedure was fundamental for shipping and therefore certain specifications regarding bunkers had to be applied in a uniform way as the quality of bunkers affect shipping operations, financial performance and of course the environment. The first use of standards took place in 1982, to be later updated in 2010 and 2017 respectively and was registered in the International Standardization Organization under the number 8217, with the current status being ISO 8217:2017. This standardization rule reflects on the technical requirement for machinery operations –e.g. flashpoint, stability cold flow etc.-, while maintaining the proper standard in aspects such as quality, safety environment and onboard storage (Ship & Bunker, 2018).

The matter regarding quality and compliance with ISO and international conventions' specifications has become of utmost importance, something proven by the details of the bunkering and sampling procedure described in MEPC.1/Circ.875/Add.1, 'Guidance on Best Practice for Fuel Oil Suppliers for Assuring the Quality of Fuel Oil Delivered to Ships', where in paragraph 3.1.1. and 11.5. (1) & (7) detailed information is provided on the method of sampling.

Thorough bunkering documentation is to be kept onboard for at least three years, containing information such as name and IMO number of the vessel receiving the bunkers, port of bunkering, date on which bunkering began, full contact information of the bunker supplier, quantity in metric tons, density, sulphur content etc., as well as a solemn declaration of the supplier regarding the sulphur content of the bunkers and the non-existence of any substance harmful to the engine/environment/onboard personnel of the vessel.

Similarly, the sampling procedure requires through documentation with the sample bottles' labels containing info such as: location at which, and the method by which, the sample was drawn, date of commencement of delivery, name of bunker tanker/bunker installation, signatures and names of the supplier's representative and the ship's representative, name and IMO number of the receiving ship, bunker grade etc. (The American P&I Club, 2019).

Chapter 3: 2020 and the road ahead: The option of distilled and new fuels.

A brief outline of the challenges the future holds for all the major stakeholders of the shipping industry, was set in the introduction. 2020 will be a landmark year for the industry, as a new path towards sustainability and compliance with the general environment protection trend will be opened through the implementation of the MARPOL Annex VI regulation regarding sulphur particles emission from the vessels' funnels. Although the demand for a shipping industry more viable in terms of its performance against the environment has been going on for decades, the steps towards achieving it have been at a fast pace only within the last decade. With 2020 just around the corner and the enforcement of the new cap at the sulphur emissions being ready to start, the stakeholders –from ship owners to refineries and charterers to traders- are not yet entirely prepared, let alone certain about the implications the new rules will have on the industry. In the following chapters, we will examine the potential solutions / options of the shipping industry to comply with the new set of rules, the major concerns existing around the old and new fuel management, as well as a potential relay change in the choice of the leading propulsion fuel that might be coming within the next decade.

3.1. A multi-fueled future for shipping

The transition to the new status quo is best described through the words of Iain White, Global Marketing Manager for Fuels and Oils of ExxonMobil in a panel under the title "Global sulphur cap 2020: risks and challenges" at Lloyd's List Business Briefing in London on October 2017:

> *"So, we are heading towards a multi-fuel future, which means distillates are relevant. There'll be blended fuels; they'll be heavy distillates; they'll continue to be some, a variety of blends of heavy oil available. They'll be the new fuels: LNG, LPG possibly, methane, we've already seen happening; and of course, you could install a scrubber and legitimately keep burning the high Sulphur fuel."*

Based on these words the need for higher quality refined products such as oils with less sulphur content is expected to rise. Market anticipates the new fuels to be broadly categorized as either Ultra-Low Sulphur Fuel Oil (ULSFO) with a maximum content of sulphur particles not in excess of 0.1% m/m or Very-Low Sulphur Fuel Oil (VLSFO), with sulphur content up to 0.5% m/m. Fuels of such emission specs exist in the market, due to the necessity for vessels to sail in Emission Control Areas, as thoroughly explained in chapter 1.3 above, however the quantities and availability are nowhere near the ones that will be needed after 1/1/2020. There relies mainly the challenge for the refineries around the world, to prepare and supply the bunkering market with adequate quantities and at a multitude of ports around the world, without overseeing the second challenge existing, which is the proper blend mixture and the side-effect minimization regarding any adverse results in the vessels' engines or other issues such as bunker safety and storage onboard.

3.1.1. Ultra-Low Sulphur Fuel Oil

ULSFO is a fuel that already exists in the market, due to the necessity of compliance with the ECA regulation of sulphur emissions up to 0.1% and is expected to gain share in the market, after 1/1/2020. This type of fuel is basically a neat product of the petroleum refining process presented above, therefore being significantly more expensive than traditional heavy fuel oil, thus presenting a challenge to the shipping companies and charterers, since it adds up on the bunkering budgets, which are already a large sum of a vessel's operations' expenditure.

Apart from the difference in the expenses of traditional heavy fuel oil and those of ULSFO, there are other technical matters that need to come to the attention of owners and managers. Since distillate fuels are lighter products, it is expected of them to have lower viscosity than residual fuels and in the case of transition from systems using residual oil for long periods to the use of distillates, potential leakages are to be closely monitored. Due to distillates not needing pre-heating in order to operate efficiently, other specializations of the fuel such as Cloud Point or Pour Point need to be taken into consideration and of course storage temperatures depending on the climate of the area the vessel operates in (ICS, 2019).

Although regulation 18.3.1.1 of MARPOL Annex VI states that fuel oil for combustion purposes should be comprised of hydrocarbons produced directly from petroleum refining, hybrid mixtures are expected to be offered and supplied, such as automotive diesel mixed with biodiesel (FAME - Fatty Acid Methyl Esters) in order to both cover the increased demand and reduce the difference in price compared to the conventional heavy fuel oil. ISO 8217:2017, whose provisions shall be applicable to the new fuels specifications -as stated in the ISO Publically Available Specification 23263/2019- provides a marine biodiesel specification with up to 7.0% FAME. Despite the guidelines published by ISO or ICS, it is considered as of utmost importance for ship owners prior to using these distillates or hybrid fuel mixtures to be in touch with engine / boiler / auxiliary equipment manufacturers in order to assert their ability to handle efficiently such products.

3.1.2. Very-Low Sulphur Fuel Oil

The creation of fuels compliant to the new cap in sulphur emissions is a challenge for refineries, as a matter of content and availability. The issue of content is related to the proper mixture of distillate and residual fuels, since there are matters to be resolved regarding the fuel's viscosity, stability and compatibility among others. Although Marine Gas Oil (or MGO) is a fuel already available and in use, the quantities produced are not sufficient for it to become the main propulsion fuel of the shipping industry due to the specialized and very expensive process it requires. Due to the necessity for hydrogen in order to reduce its content in sulphur particles, heavy investments in hydrodesulphurization units is needed from the refineries, since a complete unit of hydrogen producing unit combined with a sulphur recovery unit costs refineries approximately USD 150-200 millions, funds that are not easily secured even from the largest companies that are dealing with petroleum refining process (Ramsey M., 2017). Therefore, petroleum companies are expected to make use of their residual fuels, blending them with distillate products, thus creating quality fuels, which not only comply with the new regulations, but also come at a competitive price.

Figure 6: Common Very Low Sulphur Fuel Oil blends

Fuel	Full Name	Description
MGO	Marine Gas Oil	Distillate gas that is condensed into liquid
MDO	Marine Diesel Oil	Mix of MGO and HFO
IFO	Intermediate Fuel Oil	Mix of MGO and HFO, but with less MGO than MDO
MFO	Medium Fuel Oil	Mix of MGO and HFO, but with less MGO than IFO
LS HFO	Low Sulfur Heavy Fuel Oil	Desulfurized residual fuel oil

Source: Ramsey M., (2017), 'Low Sulfur Fuel in 2020: An overview of the projected maritime energy market'

Mixed fuels' blend ratio is expected to be at a 60% distillate fuel and a 40% being residual ones, since tests have shown that the result of this mixture lies within the new regulation's limits for sulphur emissions. However, this solution is not a panacea, as it comes with concerns regarding stability and hypersensitivity to commingling with other quality fuel oils within a vessel's tanks. For instance, all fuels contain asphaltenes that require to be suspended, in order for the fuel to produce the least possible amount of sludge within the vessel's fuel filters and separators. Failure in suspending them, may result to loss of propulsion power and eventually increased consumption, which is the very opposite to the result sought. As we saw earlier ISO 8217/217 standards are to apply to new fuels and therefore owners must turn to suppliers that can ensure that the quality standards are met. Furthermore, compatibility of fuels is a matter that should attract the attention of shipping companies, as two fuels that maintain the stability standards and are certified by ISO 8217, if mixed onboard the vessel, they will result in the same aforementioned unwanted results. This could occur easily by procuring fuels at different geographical locations with diversified content, even from the same bunker trader (ICS, 2019). Therefore, it is of utmost importance for ships' personnel or independent laboratories to conduct proper tests before the bunkering operation, in order to ensure that the fuels can or cannot be mixed, and in the latter case the fuels to be stored in separated units.

Finally the new fuels, should a shipping company decide to turn to them in order to comply with the cap, must be ensured to have all the specifications of ISO 8217/2017 regarding other special features such as particles of aluminum silicate (commonly known as “cat fines”), acid number and viscosity, while SOLAS Convention’s provisions regarding flashpoints must be met as well to ensure that the possible risk of fire or explosion remains on the lowest possible scale.

Chapter 4: A mix of new and old: Exhaust Gas Cleaning Systems (Scrubbers)

The primary aim of the up and coming 2020 “sulphur cap” regulation, as already noted and explained is to reduce the emission of gases harmful to human health and the environment. In the previous chapter there was an analysis of the first way that this goal could be achieved, the new fuels, which contain far less sulphur particles, consequently leading to less pollutant emissions from the funnels of the global fleet. Another way to follow in this quest for a cleaner and more sustainable shipping industry, gaining more and more popularity for reason analyzed in the next sub-chapters, is the filtering of the gas emissions produced by the burning of conventional fuels that are used today. These filters are the Exhaust Gas Cleaning Systems –EGCS-, or more broadly known in the industry as “Scrubbers”. In the following chapter the scrubber types, advantages and disadvantages will be presented, as they are a viable solution followed by a significant part of ship owners and managers, in order to be compliant with the new regulation.

4.1. Scrubber types and functions

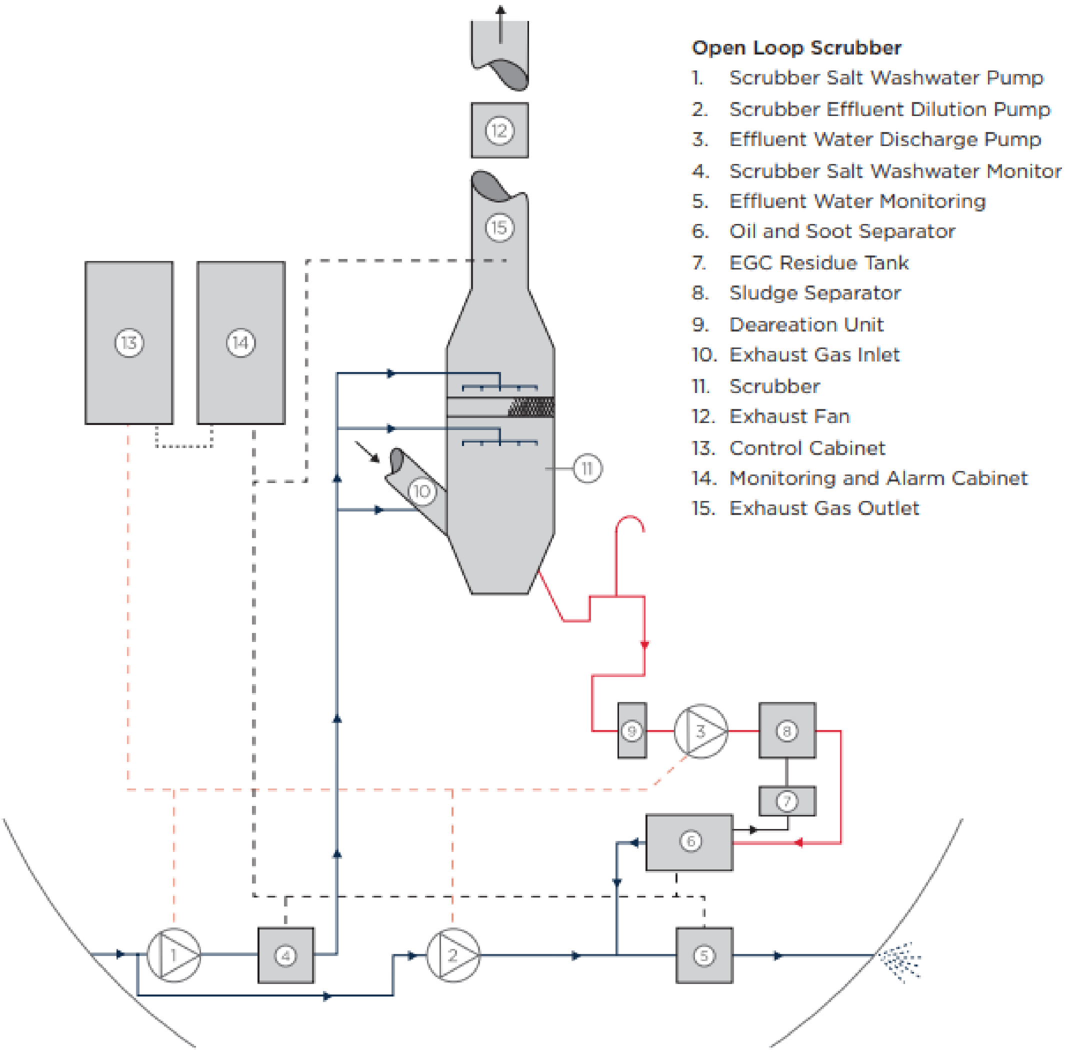
A scrubber is a device-gas cleaning system, which is installed in the vessel’s exhaust system past the main engine or boiler, processing exhaust gas with a variety of substances. These substances may include seawater, chemically treated fresh water or dry substances, eventually removing the vast majority of the sulphuric oxides from the exhaust, thus reducing polluting elements from those emissions. After passing through the scrubber system, the exhaust fume is released to the atmosphere, being compliant with the provisions of the MARPOL Annex VI regulations.

The scrubber method works based on the principle that the sulphuric oxides can be diluted in water and especially sea water, whose alkalinity converts the oxides into soluble sodium sulfate salt, which found naturally in in the ocean (ABS, 2018). In the case of navigation in rivers or sea water with low content of salt, the freshwater alkalinity is secured through chemical treatment with sodium hydroxide. Based on this procedure, one can understand that the scrubbing process is mainly a wet procedure, even though there are dry scrubbers which will be mentioned later in this chapter.

4.1.1. Open-loop –seawater- scrubber type

In this type of scrubber seawater provided by a special pump is the means used to clean up the exhaust gas. The main scrubbing process takes place in the scrubber tower, where a water separator is used to remove water particles from the gas, making the steam generation harder, preventing the gas to exit the system. The mixture of gas and seawater that is formed as the process goes on, ends up in the bottom of the scrubber, where another segregating procedure takes place removing the –now acidic- wash water from the bottom of the scrubber and after re-adjusting its pH, it is discharged in the sea, although there are exceptions to this discharge procedures, as in many places globally strict regulations apply, leading to a necessity for the above-mentioned scrubber bottom sludge to be further processed. This process includes removing elements like heavy metals, and storing them to a separate tank onboard the vessel, until they can be disposed in specialized facilities ashore (ABS, 2018).

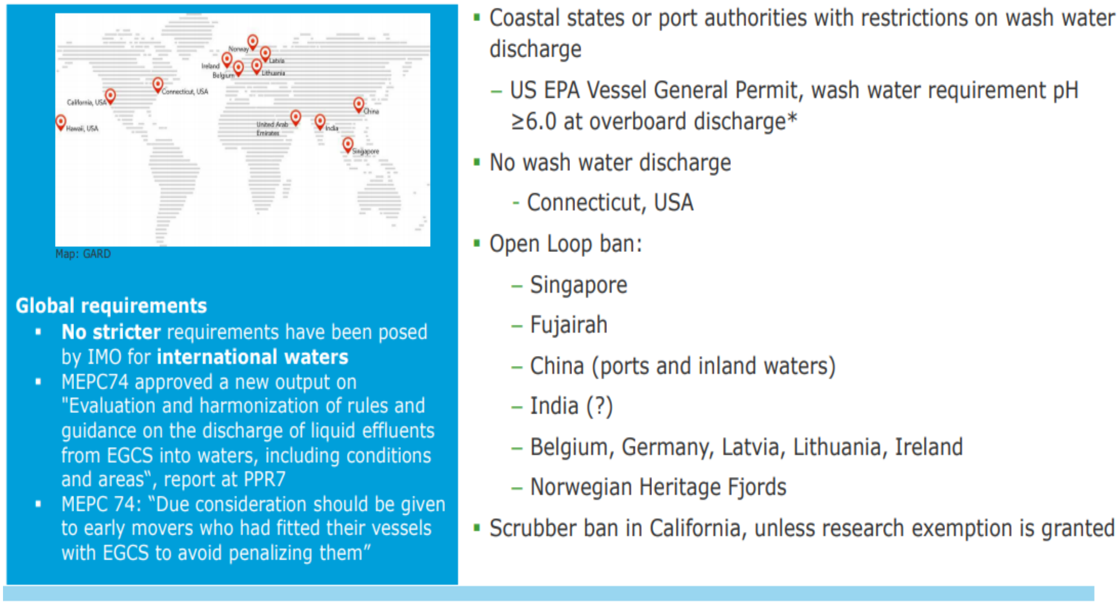
Figure 7: Open Loop Scrubber System



Source: American Bureau of Shipping, (2018), 'ABS Advisory on Exhaust Gas Scrubber Systems'

Open loop scrubbers use salty seawater as a means to the purpose of cleaning gas emissions, fact which means that the whole process relies on the alkalinity of the water in the certain area. Therefore, open-loop scrubbers will not be efficient in navigable waters of rivers and areas where seawater is not of that chemical nature, (Baltic Sea, North Sea, the Norwegian Heritage Fjords etc.), hence multiple open-loop scrubbers ban has been imposed around the world as shown in fig. 8. Due to their reliance on the seawater of the area in which the vessel trades, the use of distillate fuels will have to be employed as an alternate solution for the vessel to remain compliant with the new regulations. Ship owners or managers will have to make a decision regarding the use of the open-loop scrubber & distillate fuel combination based on the places where their vessels operate and trade. On the plus side, open-loop scrubbers are the simplest that can be fitted in a vessel, requiring only seawater in order to perform their scrubbing task, without any further treatment of the water.

Figure 8: Bans and Restrictions on open-loop scrubbers around the globe until June, 2019

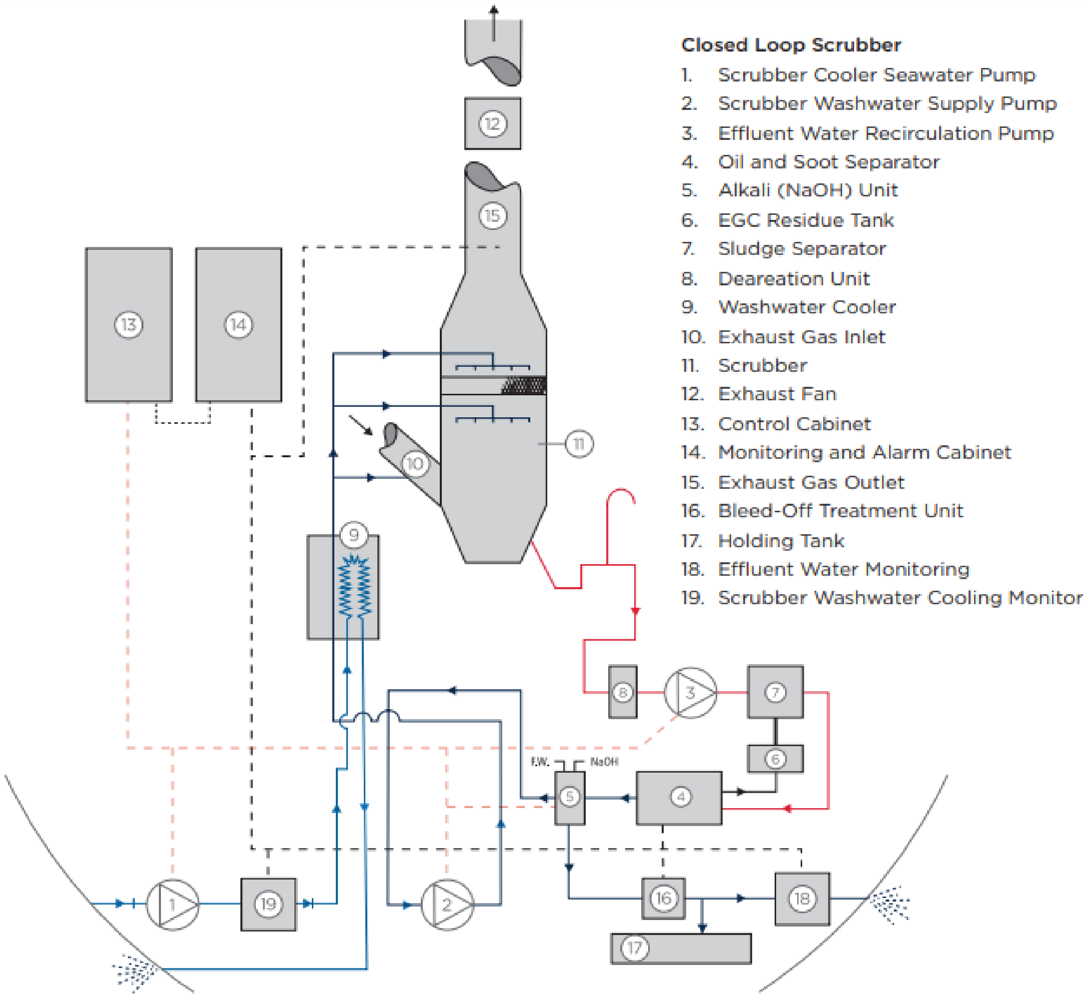


Source: Johnsen K et al., (2019), 'Global Sulphur Cap 2020 Update: External Webinar', DNV GL

4.1.2. Closed-loop scrubber type

The main idea, as well as the internal parts of a closed-loop scrubber is similar to those of an open loop scrubber. The same chemical processes to remove the SOx emissions. The major difference between the two systems is that rather than going overboard, most of the circulating wash water is processed after it leaves the scrubber tower to make it suitable for recirculation as the scrubber wash water medium (ABS, 2018). The wash water can be fresh or salt water depending on the scrubber design. In this treatment process the water used to clean the gas emissions of a vessel engine is dosed with alkaline chemical, usually caustic soda (sodium hydroxide), or the less hazardous magnesium oxide, to restore its alkalinity to the level required before the water is ready again for the procedure. A closed loop scrubber requires less than half the water amount an open-loop scrubber needs to reach the same scrubbing efficiency and also is more environmental-friendly, due to the minimum acid water disposal overboard. The reason for this is that higher levels of alkalinity are ensured by the direct control of the pH level using the alkaline chemical injection process. During these processes, the cleaned bleed-off water is discharged either overboard or to a holding tank, depending on the ship's location and local regulations. The same process as in an open-loop scrubber is followed regarding the sludge residue in the bottom tank of the scrubber, which is collected and maintained in special tanks, to be eventually delivered in specialized units ashore for further processing. The extra part in the whole procedure is the introduction of additional wash water in the alkaline mixture to replenish the amount existing before the engine gas scrubbing.

Figure 9: Closed Loop Scrubber System



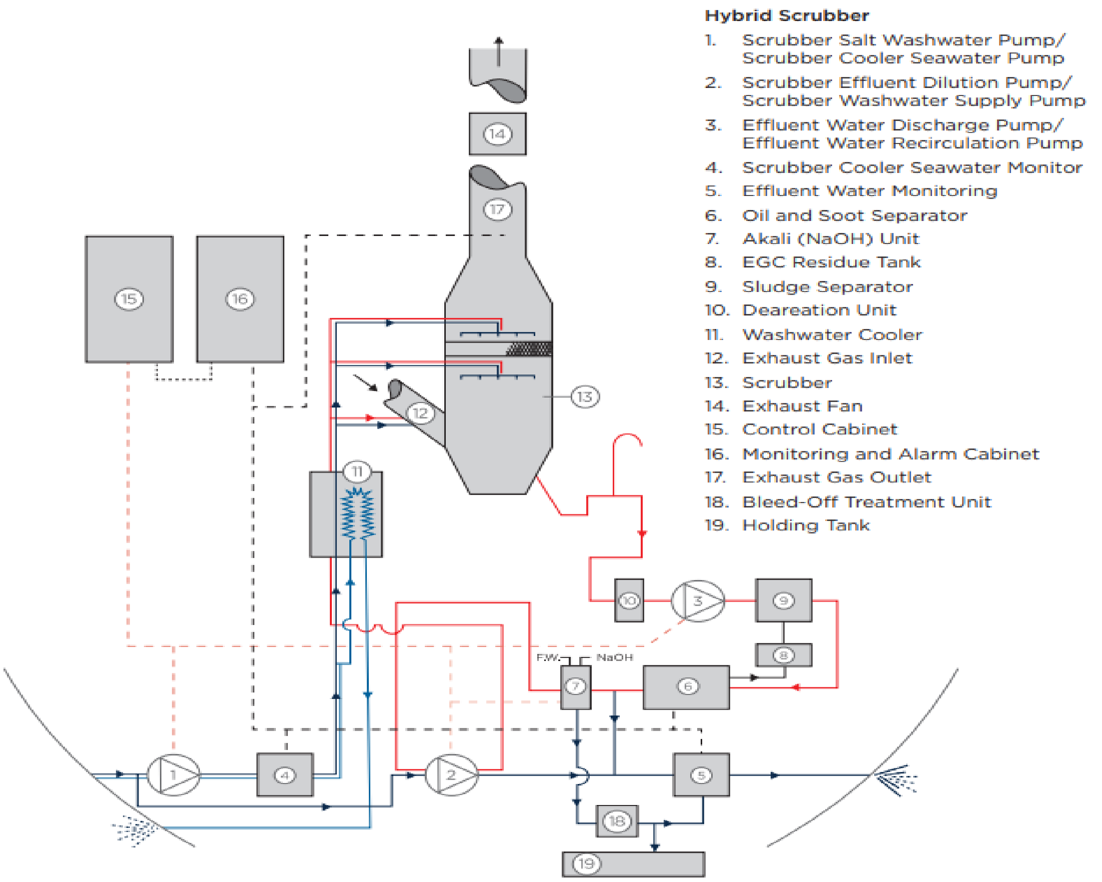
Source: American Bureau of Shipping, (2018), 'ABS Advisory on Exhaust Gas Scrubber Systems'

Closed-loop scrubbers are more efficient and independent of the seawater in the area where the vessel operates, making it viable for use in both open ocean and coastal/port areas. The disadvantages are the higher expenses due to chemical substances needed to restore alkalinity of the wash water, the increased necessity for extra space and the necessity for extra measures taken regarding crew handling the sodium hydroxide, which is highly corrosive for a number of metals, thus rendering the vessel's pipes and tanks an issue for concern and constant maintenance.

4.1.3. Hybrid Scrubbers

Hybrid scrubbers tend to combine the advantages of both open and close loop scrubbers, allowing a vessel to operate regardless of the waters it navigates in. The transition between the two modes is related to the scrubbing water circulation pump being able to switch from the one way of operating to the other. The same occurs in the switch between the two modes of wash water management –from overboard disposal mode to a circulation one-. The advantages of hybrid scrubbers are obvious, as the dual operating mode, enables the vessel to operate and trade in any area around the world. The main disadvantages are the increased costs and the slightly complicated operation of this system, since it partially embodies the disadvantages of both the aforementioned categories.

Figure 10: Hybrid Scrubber System



Source: American Bureau of Shipping, (2018), 'ABS Advisory on Exhaust Gas Scrubber Systems'

Figure 11: Compilation of features and (dis)advantages of wet scrubbers

EGCS	Pros	Cons	Application
Open Loop	• Uses seawater for scrubbing; does not usually involve storage or handling of hazardous chemical (caustic soda) • Comparatively simple system; less equipment/system compared to closed loop • CAPEX and OPEX relatively low	• Not suitable for low alkalinity water • Restriction of washwater discharge in certain coastal/port areas • Large washwater demand	• Vessels operating most of the time in the ocean/open sea • Vessels not entering areas with washwater discharge restriction
Closed Loop	• Independent of operation location – in low alkalinity water; in discharge restricted coastal/ port areas • Effluent is stored onboard for the duration that the tank volumes will permit	• Complex washwater system • Additional equipment/system for water treatment • More space required • Special care for handling and storage of NaOH solution, a hazardous substance. • Operation duration limited by effluent tank size • Relatively higher CAPEX • Relatively higher OPEX due to use of NaOH and residue handling	• Vessels trading constantly in areas with discharge restriction or low alkalinity water
Hybrid	• Significant flexibility for operating in all regions regardless of seawater alkalinity or temperature • Effluent may be stored onboard for the duration that the tank volumes will permit	• Complicated system with more components • More space required • Handling and storage of NaOH, and residue disposal for closed mode operation • Highest CAPEX • Higher OPEX due to use of NaOH and residue handling	• Both in ocean/ open sea and discharge/ operation restricted areas

Source: American Bureau of Shipping, (2018), 'ABS Advisory on Exhaust Gas Scrubber Systems'

4.1.4. Dry Scrubbers

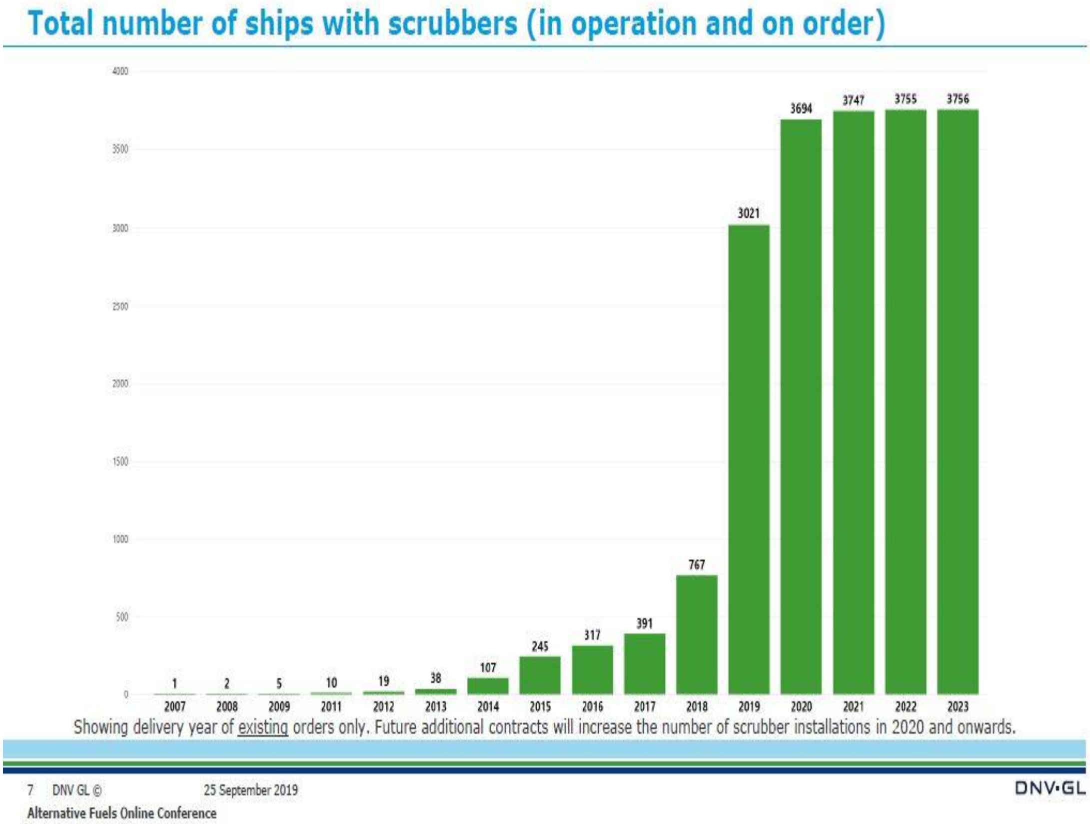
Dry scrubbers follow a different scrubbing procedure by using a dry reactant – calcium hydroxide – to remove SOx from exhaust fumes and render them in compliance with the new limits set by the MARPOL Regulation. The calcium hydroxide reacts with SOx and oxygen or water to give calcium sulphate and water. Dry scrubbing is widely used in land-based industry. A difference between marine and land-based systems is that marine systems use granulated calcium hydroxide rather than a powdered form. Trials on a 3.6MW engine using up to 1.80% sulphur content fuel are reported to have shown a 99% and 80% reduction in SO2 and particulate matter emissions respectively (Lloyd's Register, 2015).

Among the advantages of the dry scrubbing can be considered the fact that there is no wash water disposal overboard, allowing vessel operation everywhere and a very environmental-friendly procedure. The main disadvantage of this particular kind of scrubbers is the cost, due to the fact that a significant amount of space is required for the scrubber and the calcium hydroxide pellets, as well as the products of the chemical reaction of gas scrubbing. The cost-effectiveness of a dry scrubber relates strongly to how much time a ship spends in an ECA. Currently there is very limited availability of dry scrubbers compared to the proliferation of wet scrubber designs and suppliers (Lloyds Register, 2015).

4.2.Challenges presented by the installment and use of scrubber technology

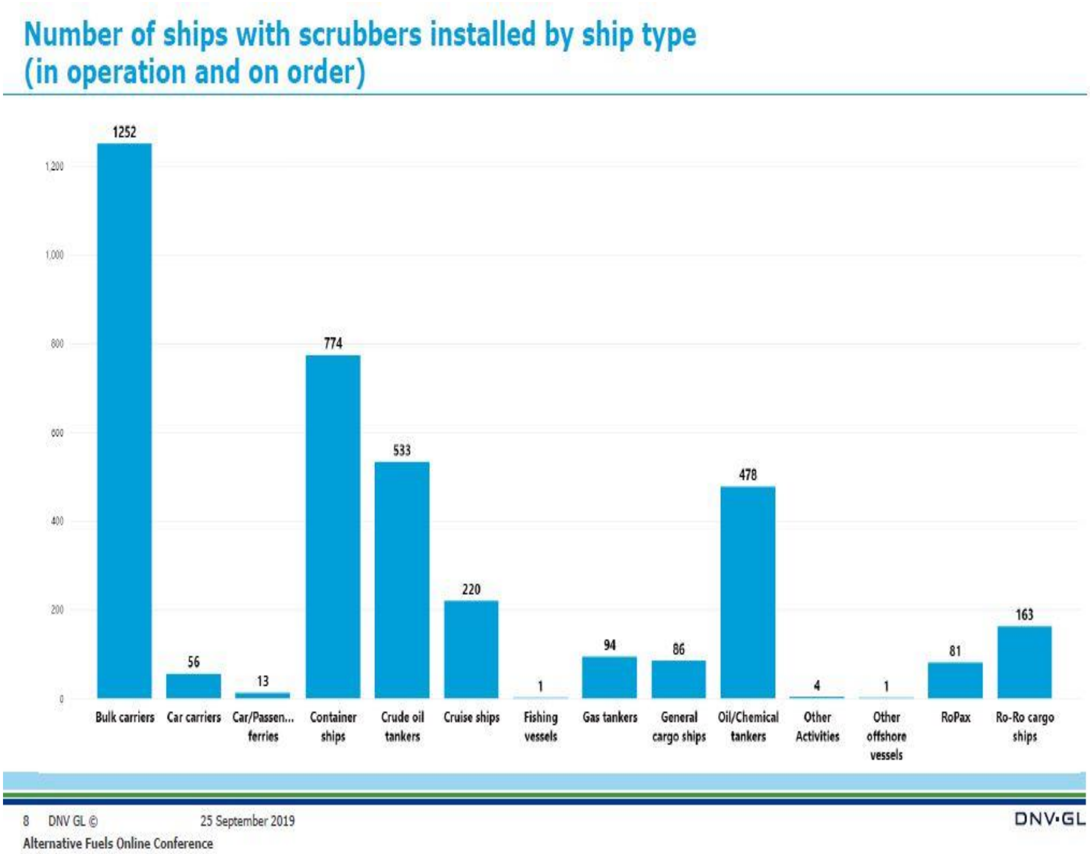
Scrubber technology is considered by many the best possible solution for the transition into the new regulation status for shipping. Evolving over the years and showing promising signs of reliability, while at the same time being available and accessible, issues that are not yet met by the new fuel oil suppliers over the world. The tendency is shown in statistics of classification societies in the following figures; however, this choice does not reside outside of the field of challenges for owners and managers that go for it.

Figure 11: Number of vessels with scrubbers fitted (Present and Orders)



Source: DNV GL, (2019), Alternative Fuels Online Conference

Figure 12: Scrubbers by ship type



Source: DNV GL, (2019), Alternative Fuels Online Conference

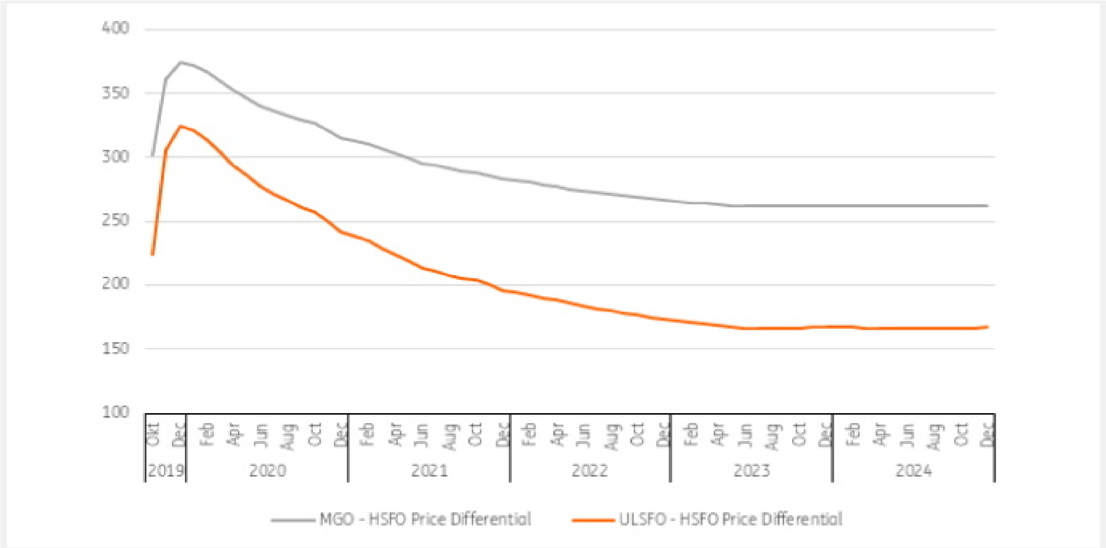
The challenges an owner faces regarding the right choice of scrubbers are of various natures and require a different way of addressing them. First of all wet scrubbers and even more dry ones are large constructions requiring a lot of useful space of the vessels to be "sacrificed". Apart from space, weight is another issue of critical importance, not only about the displacement which is affected (wet scrubbers weigh around 50-70 tons, while dry can escalate up to 200 tons), but also about the vessel's stability. Furthermore, scrubbers are retrofits on existing vessels and therefore there are potential cases of hampering the engine's performance either through the backpressure they might cause on the vessel, thus creating the need for extra fuel consumption and not serving the purpose of environment protection, which was the initial reason for their introduction in shipping. Another case of problems scrubbers may cause as a result of their function is flooding with potential hazardous effects in the main engine or the boilers. Since scrubbers are mostly a wet based cleaning system of gaseous emissions, multiple sets of pipes and pumps are involved in their operation, as shown in the diagrams of fig. 7-9-10. Seawater introduction and disposal pumps, segregation systems to split sludge from acid water for further process etc., there are many cases of potential floods due to malfunction, creating a necessity of top priority for automated systems and alarm systems for prevention of such phenomena (ABS, 2018). Last, but not least onboard challenges in the use of scrubbers are also related with the vessel's crew, who need to be not only re-trained in the use of the new technology, its potential dangers or maintenance needs, but also to have knowledge and sufficient equipment/gear to handle in a safe way hazardous materials essential for scrubbers' operation such as caustic soda (sodium hydroxide) of closed-loop scrubbers or calcium hydroxide of dry scrubbers.

However apart from technical challenges onboard the vessel, there are also challenges of financial and commercial nature for managers and owners. In an era when banks, the main finance providers for the shipping industry tend to back out from it due to its high volatility and risk, financing scrubbers could prove a hard task to accomplish. Although it can be achieved through credit from the provider or through leasing or security provision, many companies of small/medium size are expected to face difficulties in securing the necessary funds.

But the main concern regarding the option of scrubbers –and actually any option regarding the future of vessel propulsion after 1/1/2020- is about the commercial impact it will have on the company. According to a recent ING research on the matter, approximately 6% of the global fleet will be equipped with scrubbers until Q4 of 2020 (ING, 2019). Capital cost, less space available onboard, requirements for maintenance and better-trained crew are only some of the reasons why owners will not prefer this solution, in a combination with the lack of incentives to go for it, as first of all owners, especially on a time-charter scenario are not to be significantly benefited by scrubber retrofitting –except maybe from the case that they shall make their vessel more appealing in order to get hired by a charterer-. Moreover, the responsibility for compliance with the emissions regulation in the case an owner has installed a scrubber is exclusively his own, while in the case the owner uses the new types of fuel, the responsibility lies on the supplier's side.

Finally, maybe the most significant parameter of whether an owner may or may not think of following the scrubber option, in order to achieve compliance with the sulphur cap, is the investment's repayment or even profit. Despite the fact that the concept of risk is interwoven with that of investment, in this case, an owner may be facing a very hard-to-solve riddle. The reasons for this are the multiple missing parts from the equation, with the most significant of them being the employment days of the vessel and the price differential between Ultra Low Sulphur Fuel Oil / Very Low Sulphur Fuel Oil and traditional High Sulphur Fuel Oil, which currently is broadly available.

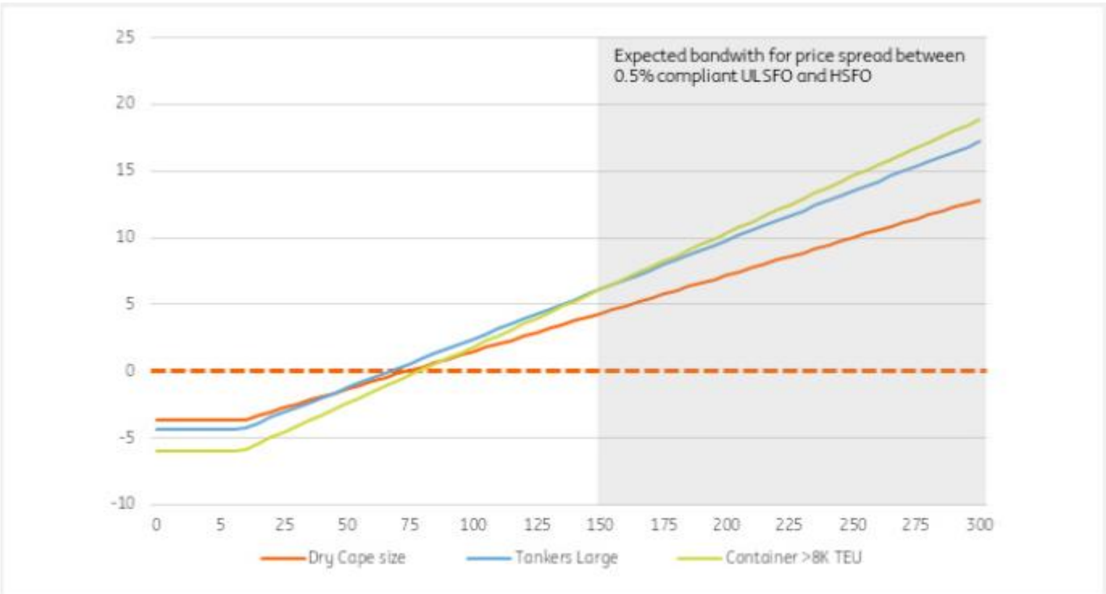
Figure 13: Expected price difference in high sulfur fuels and IMO 2020 complaint fuels



Source: ING Research Difference in forward prices between 0.1% compliant gasoil (MGO) and HSFO. Price difference between ULFSO-HSFO is an ING estimate. Spreads in US$ per Metric ton (mt) of fuel.

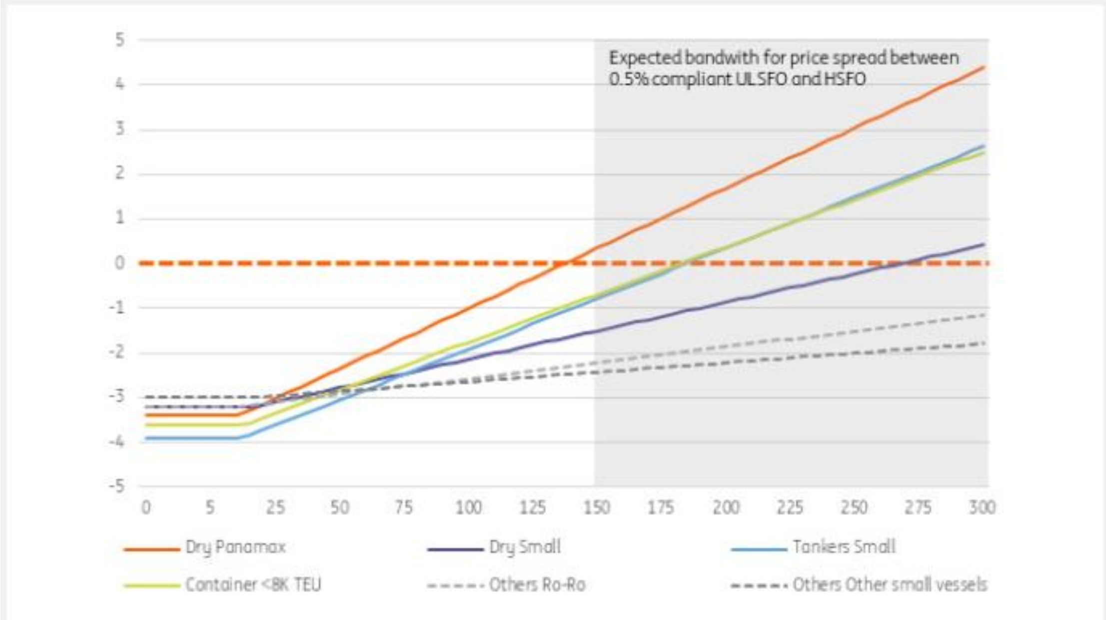
Based on scenarios like the one in figure 13, taking place in the second half of 2019, the results (fig. 14 and 15 below) are mixed. It is logical that the higher the difference between compliant fuels and traditional HSFO with scrubber installed, the faster the repayment of the investment will be. In addition to that, the size of the vessel plays also an important role, because it is observed that the larger vessels tend to have faster repayment times, while for smaller vessels (age is also a factor here), the investment does not seem to repay as fast.

Figure 14: NPV for large vessels (US$M for a given price differential between ULSFO and HSFO for vessels of DWT> 100,000 / 5-year investment horizon)



Source: Sparkman T., Luman R, (2019), 'New environmental rules reshape global shipping'

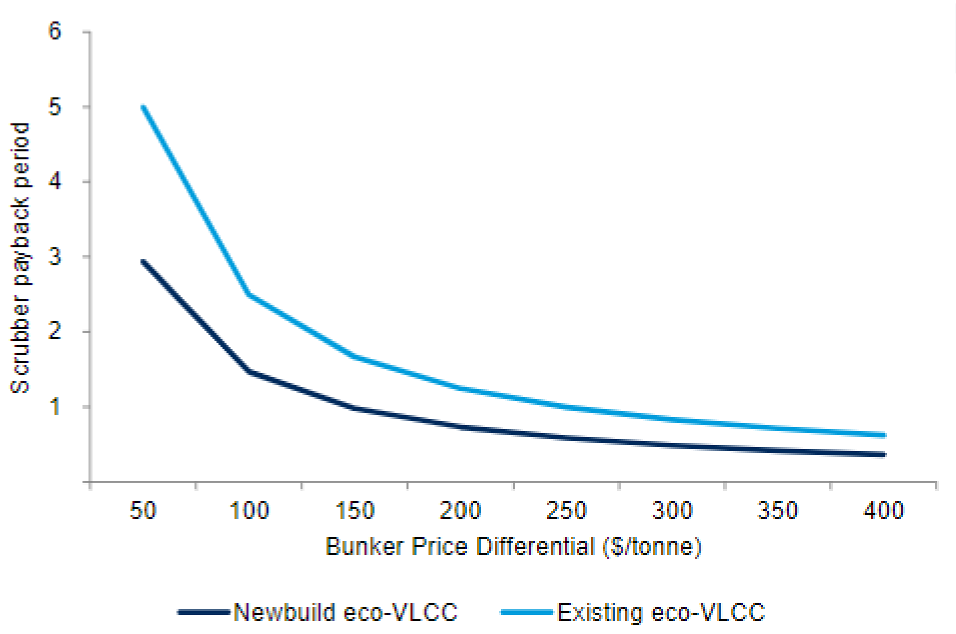
Figure 15: NPV for small vessels (US$M for a given price differential between ULSFO and HSFO for vessels of DWT< 100,000 / 5-year investment horizon)



Source: Sparkman T., Luman R, (2019), 'New environmental rules reshape global shipping'

Larger vessels appear easier to achieve positive NPV investment within the first 2 years with a spread above US$150 and within the first 4 years with a spread above US$100. For smaller ships, the NPV's are considerably lower, while for most Panamax vessels and smaller, the NPV varies between -US$1 million and US$5 million. Small tankers and small container vessels only have positive NPV from a spread of US$185 or more. If the spread between fuel prices was considered lower, there is chance for a negative NPV over a planning horizon of five years. For small-size bulk carriers, the NPV is negative in most cases. Ro-Ro vessels and other small ships show a negative NPV for any given spread, except for the case that one assumes a longer time-span for the investment (ING, 2019). One last comment on the matter would be the observation that analysts tend to agree on these matters, considering a Drewry research conducted on August, 2018 when the following diagram was presented (fig. 16) showing figures close to those of ING, regarding the repayment time of the scrubber investment on a VLCC tanker (taking as well the principle that the bigger the vessel-the faster the repayment, due to an economies-of-scale side-effect).

Figure 16: VLCC Scrubber payback period



Source: Verma R., (2018), The dilemma of fitting scrubbers, Drewry Maritime Research

Chapter 5: Does Liquefied Natural Gas hold the solution for the future of marine propulsion?

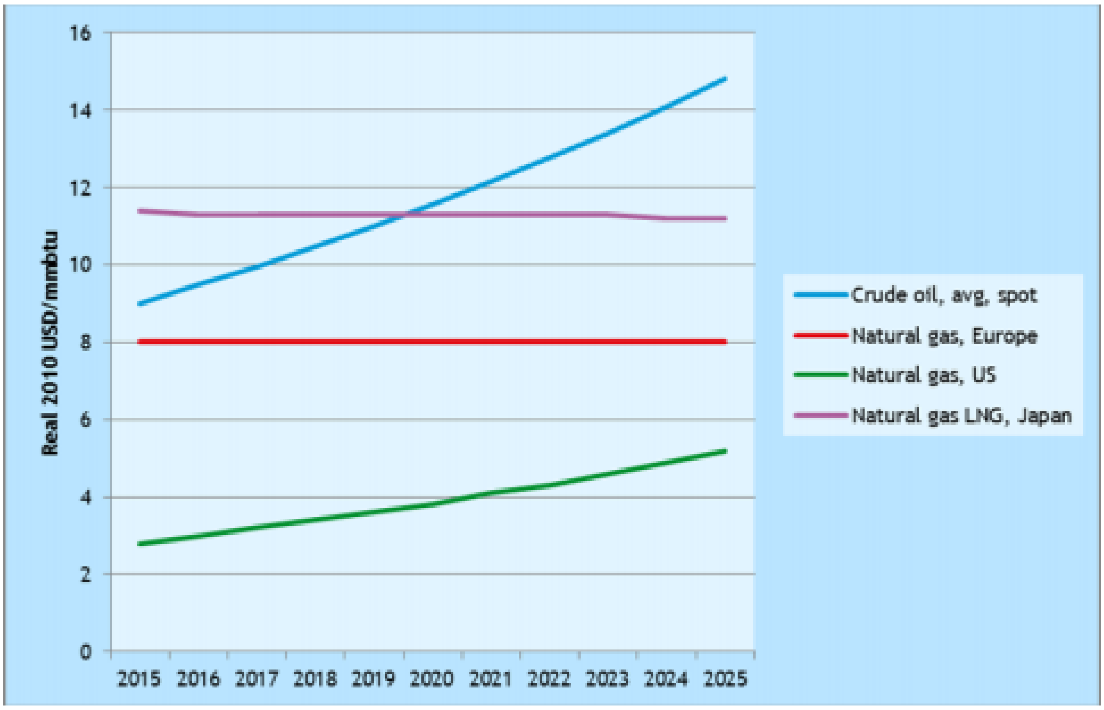
In chapter one (fig. 3) IMO's ambitious plan for GHG emissions by at least 50% by 2050 was presented, a plan which cannot go through without a fast-paced transition to "greener", yet sustainable solutions for the propulsion of the global fleet, which is constantly rising in numbers and carrying capacity. While this transition cannot happen in the blink of an eye, the gradual application of more environmental friendly solutions is a general trend, that intensifies at a fast pace. To achieve viability though, the dependency on fossil fuels cannot be stopped, as they are the most common sources of energy and their efficiency after so many years of use has increased significantly. The general environmental-awareness / sustainability trend however, seems to affect even the hydrocarbon usage, as more and more companies are turning gradually from conventional fuels to the use of Liquefied Natural Gas –or commonly known as LNG- as a main fuel for their ships. Steps towards this direction are taking up pace due to the 2020 regulation, as LNG offers a viable solution in terms of price-efficiency-compliance and availability. In this chapter we shall present and examine the LNG option for owners and managers, as a means for compliance with the "sulphur cap" regulation.

5.1. LNG properties and viability

LNG refers to a gaseous mixture of propane and butane, which under certain conditions of low temperature and high pressure can be turned into a liquid gas proper for kinetic energy production through the operation of specialized internal combustion engines (2-stroke engines or 4-stroke engines). LNG is the product of petroleum refining process, as well as mining and drying procedures, used in multiple aspects of everyday life (use in heavy industries, households, engine propulsion in cars or ships etc.). Natural Gas in liquid state has advantages for the engine burning it, since its burning process does not leave behind any residual substances hampering the engine performance, thus reducing costs for maintenance and service. In addition, it is considered due to its price and availability a viable solution for automobiles and merchant trucks.

As far as the environmental aspect of LNG use in engines is concerned, a significant reduction in CO_2 emissions has been recorded (approximately 25%), while the reduction in nitrates and sulphates is even higher reaching 85% and 90-95% respectively. These properties of LNG as an engine fuel, in combination with its current and projected market prices, which are significantly lower compared to oil fuels, make natural gas a very appealing solution for the shipping industry to turn to, in order to reduce costs and comply with the new IMO regulation and the general project of GHG emissions' reduction until 2050.

Figure 17: Crude oil and gas price projections of the World Bank



Source: World Bank Commodities Price Forecast, April 2015

Environmental effects of LNG use on a global and massive scale are under investigation through the use of projection models in order to compare potential outcomes with the goals of IMO. In a 2018-published survey of University Maritime Advisory Services (UMAS, 2018), it is stated that depending of the way LNG demand will go in the upcoming years, the reduction in CO_2 emissions could result up to 460 million tons over the 2015-2050 period, which is a step towards IMO's goal for 2050.

5.2.LNG use drawbacks

As with every effort of transition in the field of energy and consumption, multiple drawbacks are being reported or being found out in the process. LNG issues are of environmental, financial and efficiency nature, presenting challenges for its implementation as the main propulsion fuel.

First of all the *efficiency* matters are in consideration with the existing fleet. The transformation a vessel needs to undergo in order to convert from fuel oil to LNG is substantial and expensive. In addition to that, LNG's storage requirement are substantially increased compared to oil, as gas required for the same energy output requires twice the volume compared to oil. It is reported that in the case of larger vessels, the cargo space sacrificed for LNG storage can reach up to 3% (Marsh and McLennan, 2015), leading to freight losses that have impact on the expected profits of a shipping company. These reasons are of critical importance causing owners to prefer LNG burning engines at the stage of building a new vessel, rather than converting an already existing one. Another reason closely related to the efficient use of LNG-propelled is the requirement for well-trained crew, as this technology is demanding and people onboard need to have knowledge about the gas' properties, as LNG due to its cryogenic nature could cause to crew frost burns if something goes wrong, or cause cracks in metal surfaces, thus resulting to stability issues. Further hazards of LNG use could be caused by its highly flammable nature or its odorless scent which at high concentrations from a potential leakage which could lead to asphyxiation (Vandebroek L. et Berghmans J., 2012).

The drawbacks recorded are also of *environmental* nature. Although branded as the solution to a greener shipping industry, fact which could be proven true under certain circumstances, LNG has some natural characteristics that may result in a direction opposite to the one wished for. One of the main parts that form LNG is methane, which is itself a greenhouse gas, like the ones IMO wishes to reduce through the application of stricter regulations. As stated before, LNG is the cleanest-burning of the fossil fuels due to reduced carbon, sulphur and nitric emissions, however there is the concept of "methane slip", which gives rise to concerns regarding whether methane is or is not an environmentally-friendly source of energy. Methane is a GHG, which means it traps heat radiation and promotes global warming, same way CO_2 does, although according to many studies, methane is way more potent than its counterpart, leading to a significantly more adverse impact on climate change (25-30 times stronger impact than CO_2).

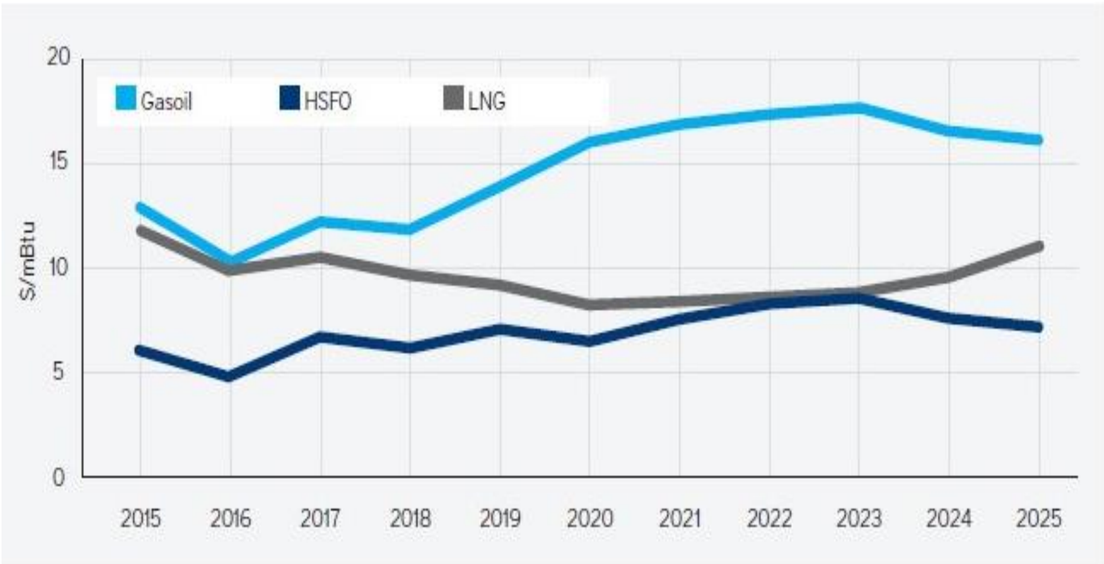
"Methane slip" in the context of LNG-powered ships occurs as a result of gas leaks during bunker transfers and also when a small proportion of the natural gas introduced into engine combustion chambers fails to burn and escapes through the exhaust system to the atmosphere (Riviera Maritime Media, 2018). Methane escaping the combustion chamber in a gas-fuelled engine as an unburned hydrocarbon is a result of a relatively failed combustion of methane due to a lean mix of methane gas and air. In order to achieve full combustion and minimum methane slip, an engine must run in a mode of high-pressurized gas injection, the way it happens in conventional diesel engines, providing results in which methane slip is almost negligible. However, in this case of full combustion in high-pressure gas injection engines (two or four-stroke), NOx emissions are not reduced enough to achieve IMO's upcoming requirements and therefore owners must provide their vessels with an additional catalytic reduction system, causing expenses to increase significantly, thus rendering the whole LNG project not really competent money-wise.

At this point it must be noted that the "methane slip" or more accurately the "Total Hydrocarbon Emissions" phenomenon, is not a vice inherent to natural gas. The THCE phenomenon and its intensity is exclusively an issue of the engine technology and especially in the engines that run on lower pressure Otto heat cycles. However, these engines are recording a fast-paced reduction in those emissions –already 65% within their first 10 years of development- and continuous research on this field will soon yield results in the form of catalysts that will prevent THC Emissions in the same we mentioned right above for reduction of NOx emissions in high-pressure combustion diesel engines (Trakakis A., 2018). Due to these constant breakthroughs in LNG marine engineering, there are many stakeholders –among them the IMO- who are advocating that natural gas is the factor which shall ensure the transition from the current status to a harmful-emissions-free future, just not immediately. The vote of confidence to LNG as the fuel of the future is shown by the choice of very large and competitive shipping companies as CMA-CGM to order nine Ultra Large Container Vessels designed to run on LNG, while ValeMax capsize iron ore carriers are designed to be LNG-ready, meaning that they will be able to convert from fuel oil to gas without requiring too much time or alterations.

Finally, challenges of financial and infrastructural nature are presented on the transition path towards LNG becoming the main marine propulsion fuel. Infrastructure is currently being developed, since for many years the LNG propulsion idea existed but there was a "chicken and egg" issue. Shipping companies had almost no incentive to invest in LNG propulsion and at the same time LNG bunkering companies would not risk expansion of their infrastructure without a strong growth prospect in this market (Smith R., Jaffe N., 2019). Today, many of the most frequented bunkering ports in the world offer, or have firm plans to offer by 2020, LNG fueling options, however the road is long to proper availability according to bunkering company officials who state that compared to supply of marine fuels in 800 ports worldwide, LNG bunkers are supplied in only 55 (Barnes B., 2018). As 2020 gets closer and the necessity for the fuel transition is about to become reality, more and more researches come forward trying to make projections and plans based on scenarios of high/limited demand for LNG. In one of those researches it is reported that up to 2019, approximately USD 500 million have been invested in marine bunkering projects within the EU only. The overall capital expenses are expected to reach USD 22.5 billion until 2050 in the scenario of high demand for LNG, while a limited demand would cause an investment amount of approximately USD 5.5 billion. The expected time of repayment of these amounts in the first case is in approximately 30 years, while the loss in the second case a more than USD 200 million loss is expected to be recorded (UMAS, 2019).

In order to assess the financial performance of these investments the key issue in the case of LNG fuel is the same as in the new fuel oils with low sulphur contents: the price spread between fuel oils –high or low sulphur- and gas. Analysts believe that LNG prices are to remain significantly lower than distillate products such as Marine Gas Oil. LNG shall remain the leading alternative to the cheap HSFO despite it will be more expensive. However, the trend shows that the environmental regulations are becoming stricter and stricter and none can be sure about the way prices will evolve in the case of some new “cap” in some other operational matter of the vessel. Finally, one must not exclude from the price fluctuation equation the potential technological breakthrough, which might create large availability in other, even friendlier to the ecosystem fuels, which will be presented in the next chapter.

Figure 18: Fuel price history and projection 2015-2025



Source: Wood Mackenzie, (2018), ‘Financing marine LNG’ by B. Barnes

Chapter 6: 2020: The beginning of the multi-fueled future of the shipping industry

In chapter 3.1, we included the statement of Iain White regarding the future of the shipping industry as far as fuels are concerned, which points out that multiple options will be available to owners and managers for their fleet's propulsion in compliance with the strict environmental regulations imposed. Climate change is already apparent and the measures to contain it should be drastic, something which is indicated in IMO's willingness to cut down GHG emissions by 50% within only 40 years (starting point of comparison is 2008). Although the first steps towards this goal is the reduction of SOx and NOx emissions through scrubbers or transition to LNG, the industry does plan ahead looking for a viable solution towards –almost- zero emissions. In this chapter these plans for alternative fuels and engineering solutions will be presented and briefly examined to provide a small picture of what the future of marine propulsion will look like.

6.1. Fuel cells and Hydrogen

Fuel cells are a technological breakthrough of alternative fuel engineering that holds a great potential in the struggle towards GHG emission reduction. Fuel cells contribute to significantly reduced CO2 emissions and zero SOx and NOx. They are considered as a clean, reliable and efficient method of producing electric power, proper for marine propulsion in merchant and cruise ships. These cells are designed to produce electricity and heat by using the chemical energy of a fuel and an oxidizing substance (Patel, 2012). Unlike conventional internal combustion engines, the fuel is not burned, hence the environmental-friendliness of this technology. Fuel cells are reported to be 50% more efficient compared to a modern diesel engine, while their silent operation, without any turbulences makes them an ideal choice for passenger and cruise ships, which are already a market for this technology, helping them enter the shipping industry without the "chicken and egg" problem –see chapter 5.2.- that LNG infrastructure building faced in the past. Another advantage of fuel cells is their ability to be placed in multiple spots onboard a ship, allowing flexibility in the power distribution towards the multiple points of interest of a vessel, especially at the stage of designing and building a ship.

Fuel cells usually use hydrogen as a fuel, although there are options to use other mainstream fuels of fossil origin such as marine gas oil, natural gas or methanol. Hydrogen is a chemical substance known for its ability to carry and produce large amounts of energy. It can be produced from multiple sources (e.g. electrolysis of water), but most hydrogen quantities are produced from natural gas reformation process. Renewable-source hydrogen production, as in the case of electrolysis of water, would indeed create a fuel whose production chain as a whole would approach zero GHG emissions, however with the current technology, hydrogen creation from sources other than hydrocarbons (natural gas), consumes vast amounts of energy and therefore does not serve the viability requirement for it to become a main propulsion fuel for the maritime industry. Hydrogen, however, is used in the most efficient way in fuel cells achieving efficiency up to 60%, while its appliance in specialized combustion engines achieves efficiency of 40% to 50% (Ryste J.A. et al., 2019). Hydrogen usage presents engineers with challenges common in cases of fuels in gaseous form, most significant of which is the storage of the fuel. Choices of compression or liquefaction through pressure and low temperatures appear to be viable; under the important condition of careful selection of storage tank materials due to the ease hydrogen reacts with a multitude of metals creating fractures and consequently leakages. On top of these issues, proper handling by experienced personnel is another source of concern, as well as creation of bunkering systems apart from land-based terminals and applications.

6.2. Ammonia usage

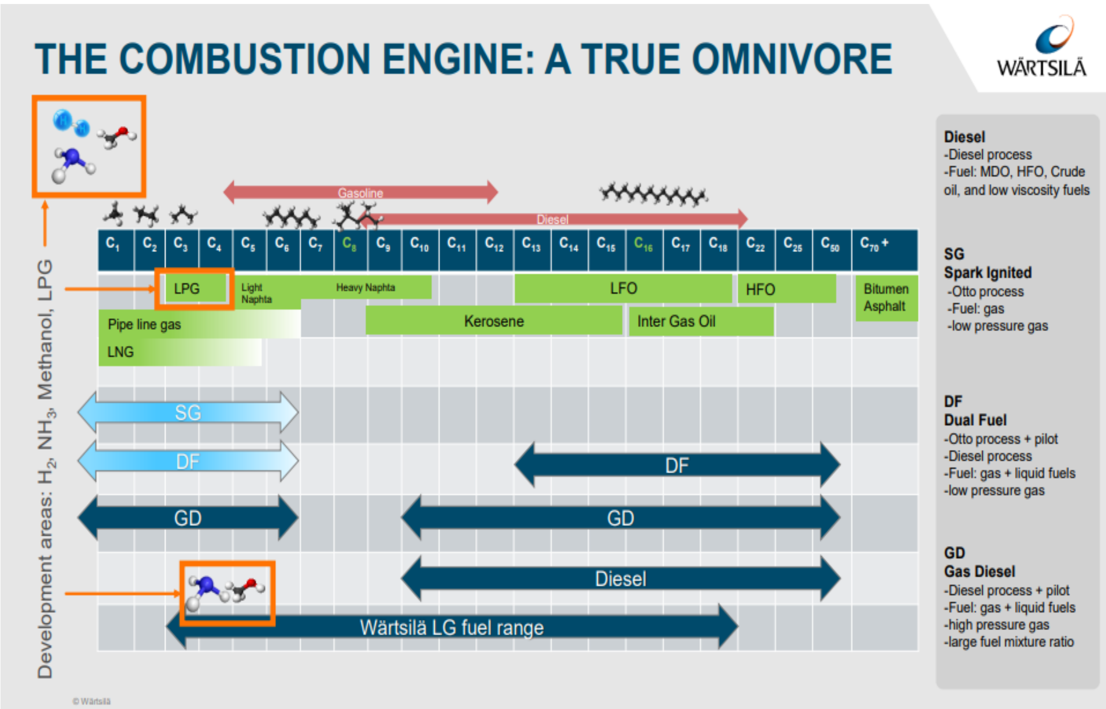
The aforementioned space/weight and safety challenges hydrogen presents in the way of becoming a mainstream energy source for the merchant fleet, has turned the industry's sights to ammonia, which has common properties with hydrogen, but alleviates the concerns due to its higher liquefaction point at -33 degrees, thus allowing easier storage and transportation, while at the same time being more energy dense than liquid hydrogen. However, ammonia does not address the issue of specialized materials that required for its storage tanks, since like hydrogen it reacts with a multitude of materials resulting to corrosion. In addition to this disadvantage, ammonia is not very efficient in combustion engines requiring the fuel cell technology to advance further in order to reap the benefits of this substance as fuel.

The way of production of ammonia determines whether it can be considered as an environmentally-friendly fuel on the industry's path to reduced GHG emissions. As in the case of hydrogen, most of the ammonia produced has its origins in natural gas, and other fossil fuel sources, it can however be produced by renewable energy sources, creating a carbon-free method of fuel production. These are the reasons that this potential fuel has attracted interest among many stakeholders in the maritime industry, who will have to overcome once again the infrastructure creation barrier (e.g. bunkering terminals), in order to increase its viability as the main alternative to fossil fuels.

6.3. Dual fuel engines and methanol usage

Another –again- rich in hydrogen potential fuel for the future is methanol. Of liquid substance and relatively cheaper in terms of technical requirements for storage, methanol is distinguished for its low carbon contents among liquid fuel options for marine propulsion. Methanol is produced from multiple sources, such as natural gas, agricultural waste, feedstock resources and coal. Although it has toxic effects for human health, in case of leakage in oceans or rivers, it is disposable and not considered as a contaminating factor. A common feature methanol has with the aforementioned hydrogen-based potential fuels is the amount of required space onboard a vessel in order to be stored and handled, while it also requires a competent and experienced crew in order to avoid health implications that might occur in case of leakage. Methanol can be applied in both two-or-four-stroke diesel engines and fuel cells, achieving energy efficiency approximating 70%, while emitting few GHG, thus being compliant with the upcoming regulations of IMO. Of course, in its overall environmental impact, one has to consider the method of its production, as coal-based methanol, despite itself being a potentially clean fuel, its method of production is reported to have twice as many GHG emissions as natural gas has while used as a fuel (Ryste J.A. et al., 2019). Methanol is already applied in various industries, including shipping (in merchant and passenger ships) due to technological breakthroughs that are being made from well-known pioneer companies in marine engineering such as MAN or Wärtsilä.

Figure 19: Wärtsilä combustion engine running on more than one fuels, including methanol



Source: Wärtsilä et DNV GL, (2019), 'Alternative Fuels Online Conference

Session 7: Fuel flexibility for ships with dual fuel engines'

In the image posted above (fig.19), a new concept of engines is presented, the dual fuel engines. This thought had been around for quite some years relating more to the use of LNG along with fuel or marine gas oil, due to the increase in bunkering prices and the upcoming enforcement of strict environmental regulations, as well as the application of the “ECA” status that we mentioned earlier. Dual fuel engines are offering convenience to shipping operators, making their vessel able to operate and trade in any area of the world, under any regulation status, usually working with a mix of fuel oil up to 15-20% and the rest of the fuel for the combustion being LNG. Now, this multi-fuel engine that Wärtsilä presents, is showing promise about allowing vessels to operate while using a wide array of fuels. This way, companies are expected to benefit from following whichever bunkering option will be more environmentally friendly, convenient, available, safe or cheap at any time given.

6.4.Bio-fuels

The increased needs of the shipping industry for clean energy sources, has led to the adoption of biofuels, especially in areas of lower emissions that require increased environmental protection. Although in limited use, the results from their application in the Norwegian short-sea shipping industry –such as ferries-, is promising, as it shows no negative results as far as GHG emissions are concerned (Stensvold T., 2015). Biofuels come in all forms, but in the case of fuels proper for marine propulsion, the case has to do more with oil and gaseous forms. Since their origins are from renewable sources, they are non-toxic fuels that can be used in combustion engines, leading to a significant reduction of the harmful emissions that comes out of ships’ funnels. Their application in shipping is limited, and primarily they are used in mixes blended with conventional fuels, although they could be used on their own, requiring only minor adaptations in parts of a ships’ main engine.

Currently there are three main categories of biofuels that are of use in the maritime sector: a) Hydrotreated Vegetable Oil –or HVO-, b) Fatty Acid Methyl Ester (or FAME, which is can also be used as a part up to 7% in Ultra Low Sulphur Fuel Oil according to ISO 8217/2017 standardization status –chapter 3.1.1.) and c) Liquefied BioGas (or LBG). Although mostly used in short-sea-shipping, last year a (short) ocean-going voyage was completed in Northern Europe using biofuels exclusively, creating prospects for the future (Adamopoulos A., 2018). The most stable and promising of the above-mentioned fuels is HVO, which can substitute fuel fossils without being in a mix with them. The major advantage is that it can be used with existing infrastructure and engines without any (or with minor, depending on the manufacturer) modifications, but the matters of availability in mass in order to serve the vast needs of the entire industry remains a question, as well as its potential price compared to conventional or other options an owner can have. Although the technology to produce them in mass is relatively limited at the moment, biofuels are expected to become a viable solution in a long term projection.

Conclusions

Even though we are only months away from the date that has been the talk of the year, on 1/1/2020 the shipping industry is about to face a "blind spot", as well as the start of a new era. The International Maritime Organization will start enforcing regulation 14 of Annex VI of MARPOL reducing the limits of nitric and sulphuric oxides' emissions at 0.5% and 0.1% in places designated as "Emission Controlled Areas". A period of preparation for the stakeholders is about to end, passing the relay to a period of understanding the new framework and realizing the way to operate in the new environmental regulation.

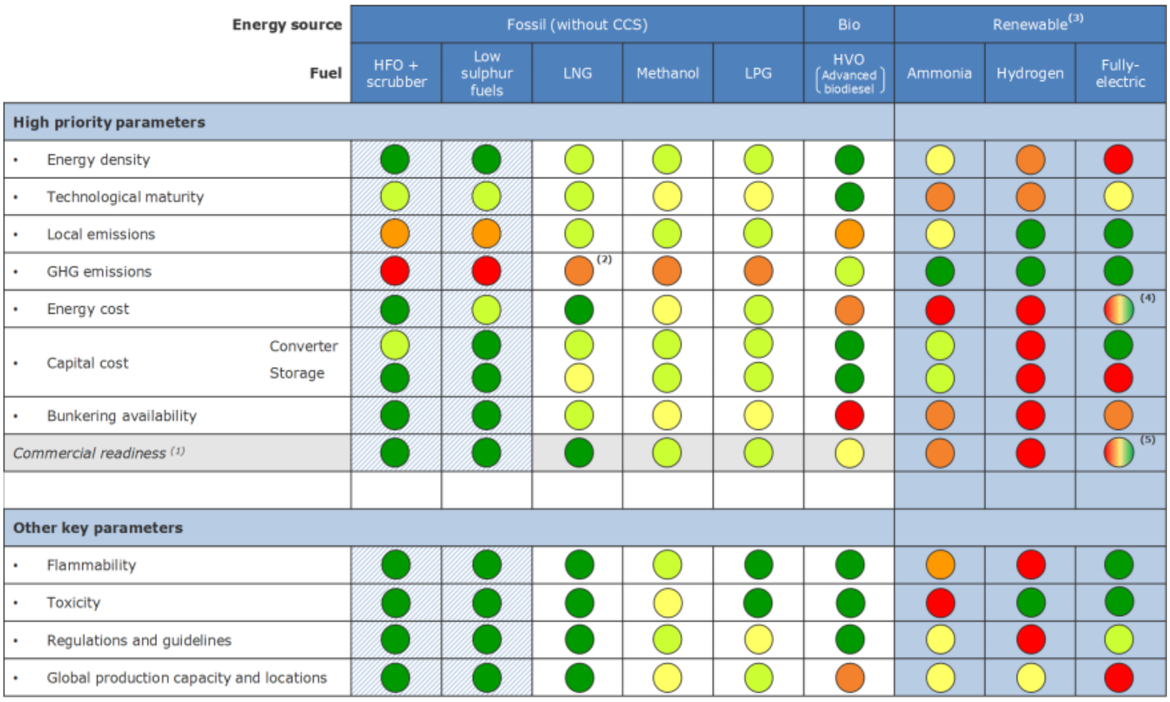
Adverse phenomena intensifying around the world, natural disasters taking place more often, ocean temperature and level on the rise are only just a few of the tokens that climate change is not a future possibility, but it is actually happening right now. Environmental awareness and protection have become a trend with more and more action being taken against it not only from individual people around the world, but also from governments, international institutions and non-government organizations. Over the last decades the IMO is working hard to improve the environmental impact of the shipping industry through the adoption of regulations regarding every possible aspect of it. The most characteristic example of the effort IMO puts towards making shipping more environmentally-friendly is the constant revision of regulation 14 of Annex VI or the MARPOL convention, which in less than a decade was thrice revised imposing stricter and stricter limits on sulphur emissions of merchant vessels, while at the same time declaring entire areas as "emission controlled", imposing almost zero limits and constantly expanding the catalogue.

Such drastic changes were anticipated to create unrest in many stakeholders, such as shipping companies, refineries, flag states, classification societies, naval architects and of course financial institutions. Fuel oil is the lifeblood of the shipping industry, but at the same time is one of the main sources of sulphur emissions, which are attributed by the IMO as dangerous to human health and the environment as a whole due to it being the catalyst for the phenomenon of acid rain, with all its adverse effects mentioned in chapter 1. Naturally the most impact would be on the shipping companies, as they would have to assess the situation created by the new regulations, review their available options in terms of bunkering, make proper financial analysis based on assumptions regarding numerous factors such as each fuel's price, availability, requirement for capital expenses in order to make the proper engine adjustments, its vessels' future employment and whether that would be mostly in SECAs and eventually come up with a strategy that would maintain their competitive advantage, or create one for themselves.

Aim of this thesis was to present the main option an owner would have in order to make his vessels compliant with the new environmental regulation, as well as their advantages, disadvantages and relevant information, along with thoughts on them. While conventional heavy fuel oil of 3.5% sulphur content filtered by a proper Exhaust Gas Cleaning System and the switch to either the significantly more expensive Marine Gas Oil or the new Ultra/Very Low Sulphur Fuel Oil of 0.1% and 0.5% respectively, remain by far the most popular choices ship owners and managers are bound to follow, in this paper it was the writer's aim to present other technologies and fuels that are gradually gaining market share. The reason for this was the fact that one must see the greater picture which is IMO's plan to cut down on greenhouse gases by 50% within only 30 years from now, a task of great importance and challenge. The long-term sustainability is the holy grail that IMO is after and it appears that the aforementioned –fossil-fuel based- solutions, although offer short-term compliance, they do not appear to serve the greater purpose and it is highly possible that in the next emission-related regulation revision they will be proved insufficient, thus adding more expenses to the shipping companies. For this reason, alternative options for owners were presented and examined, such as LNG as a marine fuel, as well as less popular energy sources *for the time being*.

Through detailed examination of bibliography and researches conducted by well-known classification societies, the outcome is that there is not one golden rule regarding the choice a shipping company must make in order to be successfully compliant with the new regulation status. Each and every one of the options above has its own advantages and drawbacks, its own way to address short term or long term viability regarding the environmental performance of a vessel and of course fits differently the profile of every company based on a multitude of factors, few of them indicated could be the profit margin shareholders would consider satisfying, company's financial profile, the age of its fleet, the way of employment (whether spot freight market or long-term time charters), the areas where the vessel spends most time etc. On top of that uncertainty regarding prices and availability of new and old fuels within a 5-year from now time frame is making planning even harder and its entirely on the company to run its tests based on projections and expectations in order to find out and make the *commercial decision* of following one or more given options to comply with environmental regulations.

Figure 20: Overall conclusions regarding the fuel options an owner can have after 1/1/2020



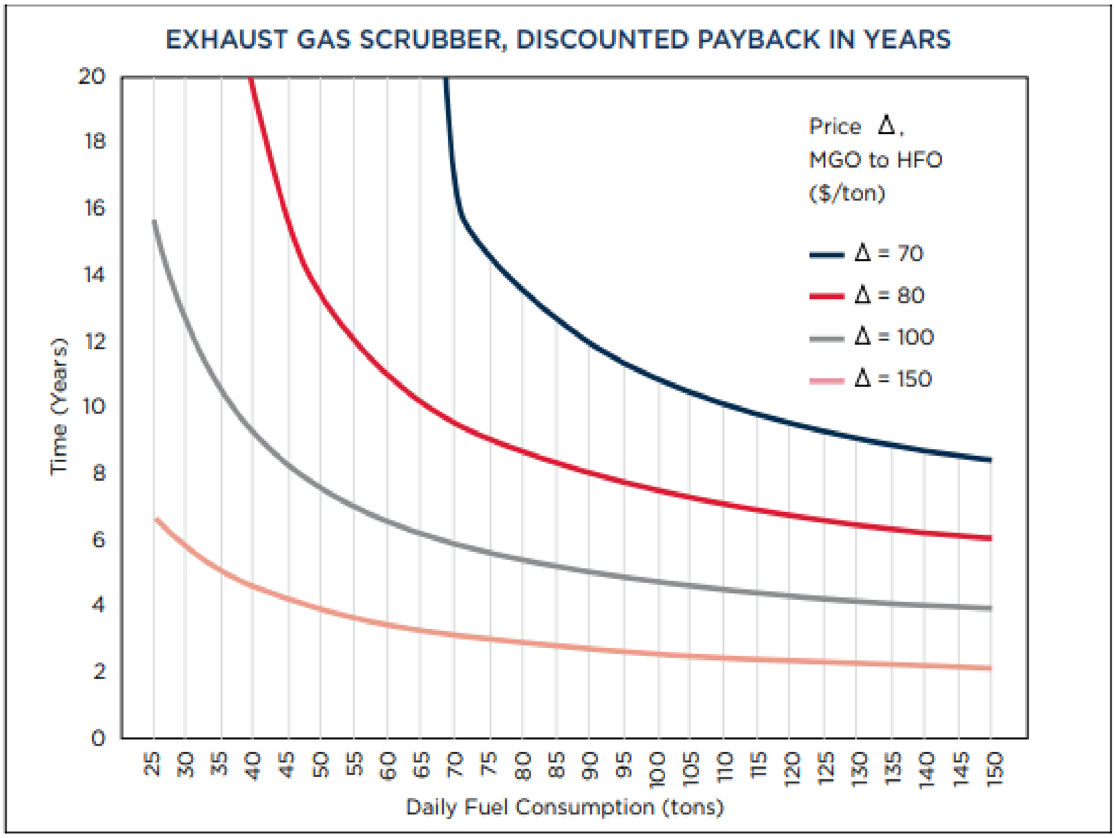
Source: Ryste J.A. et al., (2019), 'Comparison of Alternative Marine Fuels' – DNV GL

In figure 20 above one can see graphic version of all the available options an owner will have to ensure his compliance with environmental regulations. What has to be noticed and be well-noted is the "emission-cost" relationship which is in inverse proportion, as well as the "emission-availability". It is apparent that with the current technology and trends in the fuel market, an owner in order to ensure his interests would move towards solutions which are commercial ready and in the most profitable way. Even if someone would plan ahead on vessels that are currently being built in shipyards, it is anticipated that his choices would revolve around solutions up to medium commercial readiness such as methanol or biofuels, since the life of a vessel can be estimated between 25 and 35 years depending on the type and activity. Although hydrogen and fully electric propulsion are appearing as ideal solutions in the long run, serving excellent IMO's long-term plan of cutting GHG emissions by 50% until 2050, factors like energy and capital costs, bunkering availability and production capacity, are decisive against these choices, at least for the time being and on a global scale regarding deep sea shipping (since as we saw there are other cases –usually small scale- where these fuel can serve their purpose). More or less the same issues apply for ammonia as a marine propulsion fuel. Although one of the best case scenarios regarding GHG emission reduction, if produced from renewable energy sources, the matters of bunkering infrastructure and production volume remain a crucial negative factor for heading to this direction. In addition to those, current methods of producing ammonia, hydrogen and methanol, which are based on fossil fuels, do not achieve reduction in emissions, maintaining a high environmental impact and therefore technological maturity needs to be achieved in order for renewable-sourced production to increase and both environmental impact and prices to be significantly reduced.

Availability and production capacity, however, are not only a concern for the renewable or zero-emissions fuels that have still lots of road to cover in order to become mainstream. Even the conventional fuels such as HFO and LSFO are expected to face difficulties in supply, since the refineries claim that the lead time was not sufficient to fund and build the expensive facilities required to convert High Sulphur Fuel Oil to new oil meeting the demands of 0.5% emissions (O'Dell, 2019). Although gradually the new low sulphur fuel supply will increase, disruptions in prices are expected due to a very fast-paced escalation in demand in the months right before and after the beginning of the regulation's enforcement. Although this paper's aim is not to seek out the financial outcome of the comparison between the above-mentioned fuel choices an owner can make, in the next paragraph we shall make some brief considerations on the matter, in order to assist the decision-maker to make up his/her mind regarding the puzzling question "eventually which is the way?".

To assess whether the financial performance of an investment in an EGC system will turn out better than consumption of VLSFO or MGO or not, one must take into consideration three parameters: a) The vessels' daily fuel consumption, which depends on its type, size, age and maintenance, but in any case it is known in advance to the owner/manager of the vessel, b) The cost of the investment in the scrubber technology (known beforehand, as prices by the shipyards can be known as well) and c) the gap between the prices of HSFO and VLSFO/MGO, which are the point of interest, since they not only are unpredictable due to issues on supply and demand side, but also due to geopolitical tensions in the areas where crude oil is produced, thus affecting its prices. Keeping in mind the fact that the prices of VLSFO/MGO are expected to increase in the end of 2019 and the beginning of 2020, as well as the fact that cheaper prices show their impact in cases where consumption is higher, an attempt to depict the return on investment ratios will look like the graph in figure 21 below.

Figure 21: Exhaust gas scrubber investment discounted payback, according to 4 oil price scenarios



Source: American Bureau of Shipping, (2018), 'ABS Advisory on Exhaust Gas Scrubber Systems'

What figure 21 shows is that scrubber investments can be proven worthy in cases of average or large daily fuel consumptions (or simply put, medium and large vessels), with the investment returning profit in a relatively short period. This is not the case though for smaller vessels or in the event where the price margin (spread) between compliant fuel and HSFO is relatively small. As now in the dawn of 2020, the bunkering prices seem to follow the pattern regarding the price spread between the categories of marine fuels seems to be in accordance with the one in figure 13 above, although a bit higher in many cases, as we can see in the price index below on figure 23. Combining the data from the two figures, one can understand that an owner/manager who already has retrofitted the exhaust system of the vessel is to reap the fruit of the high spread between the HSFO and the compliant fuels, which can reduce the time frame within which the scrubber investment will start yielding profit even to half time (since in fig. 21 we see the maximum spread being in USD $150, while currently and for the next months the spread is going to actually reside in an area of USD 300-350 or even more). In case an owner has not already decided/programmed investing on EGCS, then perhaps it would be advisable to abstain from it, since by the time his vessel will exit the shipyard, ready to operate, it will have missed the high yielding window, as the markets will have settled and the spread between the two fuel oils' price will be reduced. In this case perhaps it would be advisable for an owner to turn to more long-term investments in LNG, as the prices are expected to remain low and IMO's struggle to achieve the ambitious goals regarding GHG emissions by 2050, will go on way beyond this year or this decade. Therefore, one must think big and plan way ahead, considering the entire lifespan of his ship.

Figure 23: Bunker prices on 06/01/2020

Last update: 2020-01-06

Nr.	Port	HSFO-380	VLSFO 0.5%	ULSFO 0.1%	MGO	Deliv.
1	Rotterdam/Antwerp	$ 300	$ 596	$ 605	$ 615	MTD
2	Amsterdam/IJmuiden	$ 310	$ 606	$ 615	$ 625	MTD
3	Delfzijl/Eemshaven/Harlingen	$ s/e	$ s/e	$ s/e	$ 665	MTD
4	Flushing/Terneuzen	$ 303	$ 600	$ 610	$ 620	MTD
5	Hamburg	$ 300	$ s/e	$ s/e	$ 650	MTD
6	Skaw Roads	$ 295	$ 615	$ 620	$ 660	MTD
7	Kaliningrad	$ 284	$ 598	$ n/a	$ 634	MTD
8	St. Petersburg	$ 193	$ 490	$ 555	$ 575	MTD
9	Murmansk/Archangelsk	$ 274	$ 578	$ 598	$ 635	MTD
10	Gibraltar/Algeciras	$ 395	$ 730	$ s/e	$ 740	MTD
11	Malta	$ 410	$ 685	$ n/a	$ 700	MTD
12	Piraeus	$ 370	$ 685	$ s/e	$ 700	MTW
13	Istanbul	$ 410	$ 710	$ s/e	$ 765	MTW
14	Las Palmas/Tenerife	$ 395	$ 700	$ n/a	$ 710	MTW
15	OPL Abidjan - Tema	$ s/e	$ 665	$ n/a	$ 730	MTD
16	Algoa Bay	$ s/e	$ s/e	$ s/e	$ 890	MTD
17	Durban	$ 335	$ 740	$ n/a	$ 790	MTD
18	Fujairah	$ 320	$ n/a	$ n/a	$ 815	MTD

Source: Petrol Bunkering & Trading, (2020), Price Index

Another issue looming in the case of new fuels is the compatibility between the mixes that will be created in different locations of the world, which as explained in chapter 3, they might be ISO 8217 compliant, but incompatible among them. Finally, an issue that might come up –not immediately, but in due time- is the availability in high sulphur fuel oils that are designed to be used with scrubbers. If in a couple of years the price spread between conventional and new fuels is deemed manageable for shipowners, then a major transition towards them would reduce the supply in old conventional fuels, as refineries –themselves being a stakeholder in such a major shift of balance in the shipping industry- will have to upgrade their facilities and focus on the most profitable solution, thus rendering a scrubber investment non-profitable any more.

In the whole quest of finding the right solution for complying with IMO 2020, one must take into consideration the role of financial institutions as well. Due to the expensive nature of all possible options –especially considered not in terms of a single vessel, but in terms of an average 10-vessel fleet, if not more-, financial institutions such as banks will be sought out to assist with funding and loans, increasing consequently owners' exposure to debt. Especially owners that will turn to long-term planning with technologies that are currently under development or towards achieving extra efficiency, they will face even higher investment needs for their new-buildings or the retrofits in relatively young vessels. In this capital loss the increase in insurance premiums must be considered as a sure upcoming event too, due to the increase of potential risk (engine damages by non-compliant fuel mixtures, scrubber failures, bankruptcy etc.).

While concluding this thesis, it is important to understand that the future of shipping will be multi-fueled, as presented throughout the chapters. The trend of environmental protection is constantly getting more and more attention and stakeholders are getting to understand that they should do something with impact, in order to counter the adverse consequences of climate change. It is expected to see heavy investments towards this direction in the upcoming years and the transition to be much more fast-paced than what anyone would anticipate. Another issue of critical importance to understand is that shipping companies cannot rely on one solution for their compliance with the new regulative framework. The rules will gradually become stricter and therefore companies must plan ahead. Depending on the factors mentioned above, which are unique for each manager or owner, companies must evaluate and quantify their profits and losses and follow the most profitable path. As the time goes by the markets and prices are fluctuating more and new breakthroughs information are re-shaping everything we considered as data until a moment ago. It is beyond doubt that literature must continue to gather data and analyzing them towards finding out the best solution of compliance and that the field for students and scientists is vast.

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